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NOTES  
ON

# CONFERENCE ON PROPERTIES OF ALKALI METALS

HELD AT  
BATTELLE MEMORIAL INSTITUTE

APRIL 24, 1961

RMT3631

*See attached*

NOTES  
on  
CONFERENCE ON PROPERTIES  
OF ALKALI METALS  
held at  
BATTELLE MEMORIAL INSTITUTE

*Herman Schwartz* April 24, 1961 *54 p refs*

under the sponsorship of

LEWIS RESEARCH CENTER  
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Herman Schwartz, Chairman  
Alexis W. Lemmon, Jr., Vice Chairman

1097005

Battelle Memorial Institute  
505 King Avenue  
Columbus 1, Ohio

June 22, 1961

Attendees of Conference on  
Properties of Alkali Metals

Enclosed are two copies of the "notes" of the Conference on Properties of Alkali Metals which was held at Battelle on April 24, 1961. My apologies for taking so long to get this material to you, but assembling the contributions was postponed a number of times for "more urgent" activities. However even at this late date I hope that you find the information useful.

No attempt has been made to edit or revise the material submitted. It has been reproduced as received except for identifying some contributions with the author and company names.

It was a pleasure to have you at Battelle as our guest, and I hope that you will visit again when the opportunity arises.

Very truly yours,

Alexis W. Lemmon, Jr.  
Project Coordinator

AWL:JM  
Enc.

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AGENDAConference on Properties of Alkali Metals

April 24, 1961

Battelle Memorial Institute  
505 King Avenue  
Columbus 1, Ohio

Herman Schwartz, NASA-Lewis Research Center, Chairman

Alexis W. Lemmon, Jr., Battelle Memorial Institute, Vice Chairman

- 9:00 Welcome - Dr. B. D. Thomas, President, Battelle Memorial Institute  
9:05 Introductory Remarks - Herman Schwartz (NASA)  
9:15 NASA Alkali Metals (Loop) Program - Arthur Glassman, NASA-Lewis Research Center  
9:45 Surveillance of Properties - W. D. Weatherford, Southwest Research Institute  
10:15 Discussion  
10:30 Coffee Break  
10:45 Battelle Program on Properties of Potassium  
Introduction and Vapor Pressure - A. W. Lemmon, Jr.  
11:00 P-V-T Properties - W. H. Mink  
11:15 Specific Heat (Liquid) - H. W. Deem  
Thermal Conductivity (Liquid) - H. W. Deem  
11:35 Viscosity (Liquid and Vapor) - E. H. Hall  
11:50 Discussion  
12:10 NASA-Lewis Research Center Properties Program - Louis Rosenblum  
12:25 Discussion  
12:30 Lunch  
2:00 NRL Sodium Program - Jack P. Stone  
2:40 Discussion  
2:50 Oak Ridge Program - Herbert W. Hoffman  
3:10 Aerojet-General Nucleonics Program - Ray W. Carpenter  
3:30 P & W Program - Robert Cleary  
4:00 Columbia University Program - C. F. Bonilla  
4:20 Discussion  
4:50 Recapitulation by Vice Chairman - Alexis W. Lemmon, Jr. (Battelle)  
5:00 Adjournment

LIST OF ATTENDEESConference on Properties of Alkali Metals

April 24, 1961

Dr. C. F. Bonilla  
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Fluid System Components Division  
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Cleveland 35, Ohio

Lt. John A. Roth  
Wright Air Development Division  
Wright Patterson Air Force Base, O.

BATTELLE ATTENDEES

Mr. Hyman Marcus  
Chief, Thermodynamics Section  
Physics Laboratory  
Materials Central  
Wright Air Development Division  
Wright Patterson Air Force Base, Ohio

Dr. Frank C. Croxton  
Technical Director

Herbert W. Deem  
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Robert B. Filbert, Jr.  
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Oak Ridge, Tennessee

Eugene M. Simons  
Engineering Mechanics Division

Dr. B. D. Thomas  
President

Mr. C. T. Ewing  
U. S. Naval Research Laboratory  
Washington 25, D. C.

## ALKALI METALS PROGRAM\*

Fluid System Components Division  
Lewis Research Center

The alkali metals appear to be the logical choice as working fluids for auxiliary power systems for space vehicles. The Fluid System Components Division at the Lewis Research Center has undertaken a number of studies for the purpose of developing such systems. These studies require reliable data on the physical and thermodynamic properties of the candidate working fluids. A brief outline of these studies follows:

## 1. Flash Vaporization Facility

Fluid: Sodium

Maximum Temperature: 1700°F - liquid (30 psia)  
1620°F - vapor (15 psia)

Purpose: To study operational characteristics of a two-phase loop, nozzle expansion characteristics of sodium vapor, material corrosion and erosion, instruments for high temperature alkali metal systems, and possibly boiler instability and phase separation.

## 2. Turbine Facility

Fluid: Sodium

Maximum Temperature: 1620°F - liquid and vapor (15 psia)

Purpose: To study and develop a turbine (150 hp) for sodium service.

## 3. Pump Facility

Fluid: Sodium

Maximum Temperature: 1700°F

Maximum Pressure: 275 psia

Purpose: To study and develop mechanical pumps for high temperature sodium systems.

## 4. Heat Transfer Facility

Fluid: Potassium, Sodium

Maximum Temperature: 1700°F - liquid)  
1700°F - vapor ) Potassium

2500°F - liquid)

2200°F - vapor ) Sodium

Purpose: To study forced convection heat transfer with and without boiling.

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\*Presented by Arthur J. Glassman, Turbodrives Section

## 5. Condenser Facility

Fluid: Potassium, Sodium

Maximum Temperature: 1700°F - liquid and vapor

Purpose: To study condensation of alkali metal vapors.

## 6. Radiator Facility

Fluid: Potassium, NaK, possibly Lithium

Maximum Temperature: 1600°F

Purpose: To study thermal radiation and condenser-radiator configurations.

## 7. Bearing Facility

Fluid: Sodium

Maximum Temperature: 1550°F

Purpose: To study the behavior of journal bearing and thrust-type bearing materials in liquid sodium at high speed.

## 8. Seal Facility

Fluid: Sodium, possibly Potassium and Rubidium

Maximum Temperature: 1600°F

Purpose: To study seal materials and designs for use in sodium systems.

## SURVEILLANCE OF PROPERTIES OF INORGANIC ENERGY-CONVERSION AND HEAT-TRANSFER FLUIDS FOR SPACE APPLICATIONS\*

Presented by W. D. Weatherford, Jr.  
Southwest Research Institute  
San Antonio, Texas

The program on energy-conversion and heat-transfer fluids was begun in 1959 under the sponsorship of the WADD Propulsion Laboratory, and a properties handbook was issued in December 1959, as WADC Technical Report 59-598 (ASTIA Document AD 230-065). The project is now being continued under the sponsorship of the WADD Applications Laboratory for the purpose of extending the coverage to additional fluids and of reappraising and revising, if necessary, the information presented previously. Emphasis is placed on the condensed and vapor phases of mercury, cesium, rubidium, potassium, NaK, sodium, lithium, bismuth, lead, sulfur, aluminum bromide, and lithium hydride, and on the gases, helium, hydrogen, and argon. Temperatures ranging from 350°F to 2300°F for mercury and 4500°F for lead and pressures ranging from less than one atmosphere to greater than 20 atmospheres are of specific interest. The properties of interest include vapor pressure, density, viscosity, surface tension, electrical resistivity, thermal conductivity, specific heat, latent heat, thermodynamic interrelationships, ionization potential, dielectric constant, magnetic susceptibility, nuclear cross sections, and corrosion characteristics.

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\* This project is sponsored by Wright Air Development Division, Air Research and Development Command, United States Air Force, Contract No. AF 33(616)-7206.

NOTES ON  
ENGINEERING PROPERTIES OF POTASSIUM

BATTELLE MEMORIAL INSTITUTE

April 24, 1961

INTRODUCTION AND SUMMARY\*

At the present time Battelle is performing research for NASA to determine the "Engineering Properties of Potassium" under Contract NAS 5-584. NASA's interest in potassium stems from its possible application as a working fluid in nuclear electric-generating systems for electrical power outputs in excess of 100 kw.

This program was initiated at Battelle on October 1, 1960, to perform measurements of vapor pressure, liquid specific heat, liquid thermal conductivity, vapor viscosity and liquid viscosity. Recently, on March 15, 1961, authorization was received to begin work to determine experimentally the P-V-T properties and vapor specific heat. In addition to the experimental data to be obtained, heat of vaporization, vapor association, enthalpy, and entropy will be computed.

On the parts of the program originally initiated, equipment is being planned and built for all experiments except the measurement of the vapor viscosity. Planning of the apparatus for the measurement of P-V-T properties began recently and only preliminary designs are known.

It is expected that data on the vapor pressure, liquid specific heat and liquid viscosity will become available about the end of this summer, but data from the remaining portions of the program will not be available in any quantity until the summer of 1962.

EXPERIMENTAL MATERIALS\*

Materials of Construction

A number of high-temperature metals and alloys were considered for possible use as materials of construction with potassium. Stainless steel, Haynes alloys, Hastelloys, Stellites, Udimets, Fe-Cr-Al alloys, Inconel, molybdenum, and various niobium alloys containing one or more of the alloying constituents molybdenum, titanium, tungsten, and zirconium were selected as possible candidates. Of these, information on behavior when in contact with potassium existed for only stainless steel and the niobium-1 per cent zirconium (Nb-1Zr) alloy. However, this information was based on exposure at 1600 F and below for the Nb-1Zr alloy and below about 1800 F for stainless steel. Some stainless steels, e.g., Types 316, 347, 304, had proven unsatisfactory

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\*Presented by Alexis W. Lemmon, Jr.

above 1600 F but quite suitable below this temperature. The Nb-1Zr alloy was evidently satisfactory well above the highest temperature investigated, 1600 F.

When used with other alkali metals, this alloy performs satisfactorily if the oxygen content of the alkali metal and of the protective atmosphere is sufficiently low.

At present, all equipment for use above 1600 F in contact with vapor or liquid potassium is being fabricated from the Nb-1Zr alloy. Some equipment for use at low temperatures has been fabricated from Type 304 stainless steel. The need for protecting the Nb-1Zr alloy from oxygen or other oxidizing materials, even in extremely low concentrations, its high cost (about \$60 to \$120 per pound), and its availability in an extremely limited number of shapes and sizes are problems which are being faced in designing and building the experimental equipment.

Extrapolation of available data on the Nb-1Zr alloy indicates that the 100-hour stress rupture value for 2100 F is about 13,500 psi.

The successful boiling point experiments were made in a quartz system with the molten potassium contained in Type 347 stainless steel. Exposure temperatures ranged to about 790 C, and performance was satisfactory. However, this is not believed to be a good evaluation of quartz as a material of construction because there was no evidence that molten or gaseous potassium came in contact with the quartz. The equipment has not been inspected since the run.

It has been fairly definitely established that a mullite ( $3\text{Al}_2\text{O}_3 \cdot 2\text{SiO}_2$ ) tube will not resist the action of potassium vapor (and possibly molten potassium as well) at temperatures of about 550 C. This experience was established in a series of unsuccessful transpiration experiments. Thus, the decision that stainless steels, e.g., Types 316, 347, and 304, would be used for applications below 1600 F and Nb-1Zr alloy for applications to 2100 F still appears sound. In addition, quartz may be useful at low temperatures, but this has not yet been validated.

Some additional verification of the suitability of the Nb-1Zr alloy for use with potassium is expected shortly upon completion of the specific heat capsule tests.

### Potassium

An important consideration in this experimental program is providing pure potassium or potassium of known purity for use in making the experimental measurements. Not only must suitable potassium be obtained, but also it must be transferred into the various items of experimental equipment without contamination and maintained in a pure state throughout the course of each series of measurements. The most critical impurity is considered to be oxygen.

Purified potassium is available from MSA Research Corporation, Callery, Pennsylvania. Two 1-gram samples were obtained directly from MSA, individually packaged in glass ampoules, for analysis. These potassium samples

were analyzed for oxygen by the mercury amalgamation method. The oxygen content of the samples was found to be  $<5 \pm 5$  ppm, believed to be quite adequate for all parts of the experimental program.

For the tests performed thus far, the purified potassium obtained from MSA in glass ampoules has been used. However, transfers to experimental equipment in a helium dry box have been difficult, and there is no way to ascertain the oxygen content of the potassium after it has been loaded.

For these reasons, it has been decided to adopt an entirely different technique. Potassium will be purified and distilled into glass ampoules at Battelle. Each lot will be analyzed before use in any experiment and, to prevent any contamination, the potassium will be transferred to the experimental equipment by using a completely closed, vacuum-tight system. The basic designs being used for a distillation column and a loading device at NASA-Lewis Research Center are being considered, although some changes have been made and other suggestions for improvement are being evaluated.

#### MEASUREMENT OF VAPOR PRESSURE\*

This phase of the program is concerned with establishing the pressure variation of potassium vapor with temperature, as well as determining the degree of association of potassium atoms in the vapor phase. Progress to date in this program has included an appraisal of the literature on potassium vapor pressures and the performance of exploratory boiling point experiments from which some preliminary data were obtained.

#### Transpiration Experiments

The transpiration apparatus which has been used to determine vapor densities is shown in Figure 1. An inert carrier gas is caused to flow slowly over the surface of the material to be investigated. The inert carrier gas becomes saturated with the vapor, and in this state enters the condenser. This condenser (which has a small orifice for the entrance of the saturated carrier gas to minimize possible diffusion effects) is at the temperature of the sample at the orifice and at room temperature at the discharge end. The vapor condenses out of the inert gas in passing through this condenser. The exit temperature is chosen low enough that no vapor remains in the carrier gas when it leaves the system. The carrier gas is metered to determine the total volume.

Upon completion of an experiment the condenser is removed and its content is assayed by weighing or by an analytical technique. If the vapor pressures can be determined by an independent method, a value for the mass of the condensed vapor and the moles (volume) of carrier gas from a particular experiment will yield the molecular weight. Applying Dalton's law

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\*Presented by Alexis W. Lemmon, Jr.



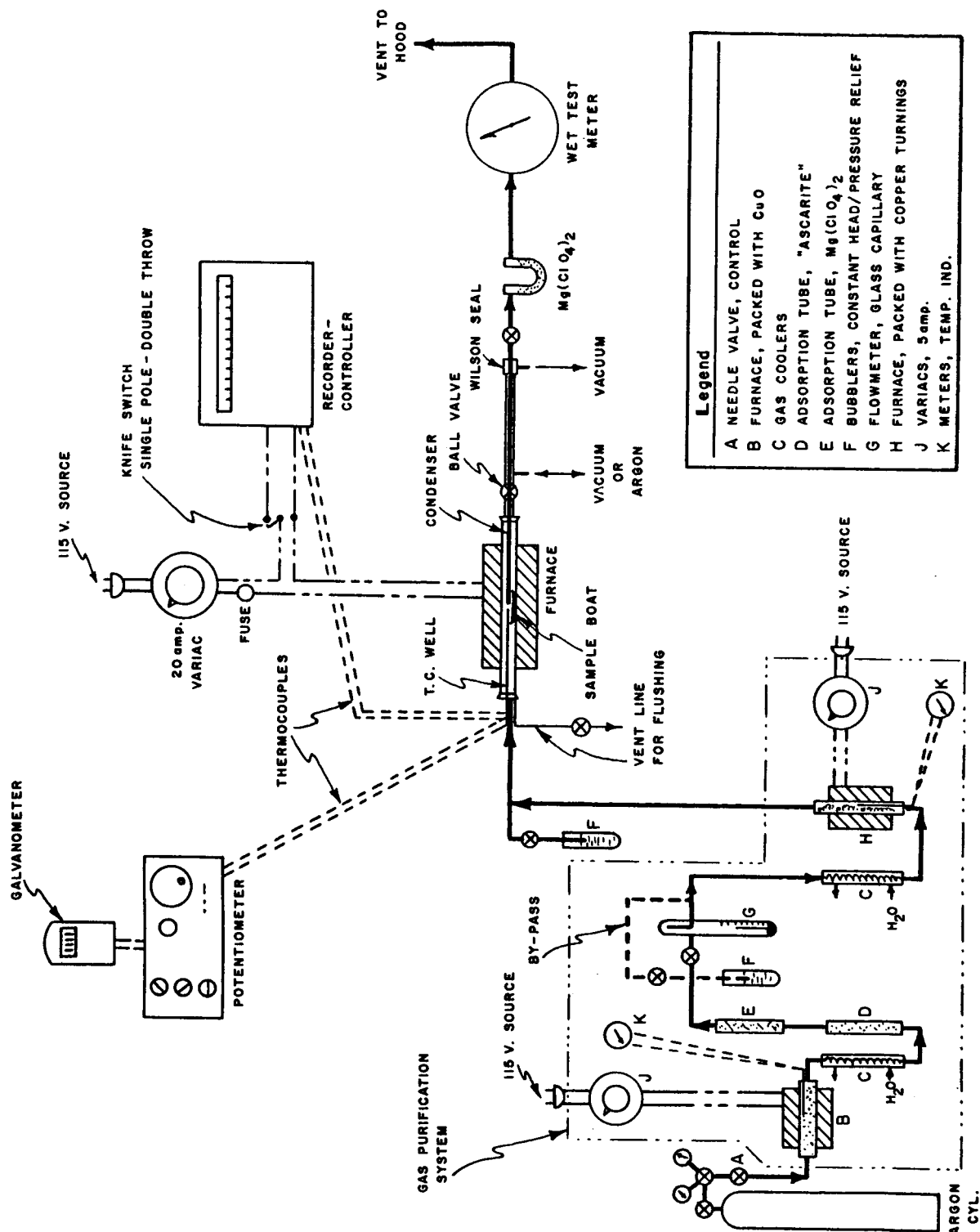


FIGURE 1. DIAGRAM OF TRANSPIRATION VAPOR PRESSURE APPARATUS

of partial pressures, the equation relating these various factors can be expressed as:

$$\text{Vapor Pressure} = \frac{\frac{\text{Mass of Condensed Vapor}}{\text{Molecular Weight}}}{\text{Moles of Carrier Gas} + \frac{\text{Mass of Condensed Vapor}}{\text{Molecular Weight}}} \times \text{Total Pressure.}$$

All values are known except the average molecular weight of the vapor, which can then be calculated.

Three transpiration runs were started, but each failed by clogging of the condenser orifice with molten potassium. The experiment was discontinued when a hairline crack developed in the mullite tube housing the apparatus. Clogging is believed to have been caused by creep of the molten potassium. This has been observed with high-surface-tension materials in previous investigations.

Following the failure of the initial experiments the transpiration apparatus was rebuilt, using a stainless steel tube in place of the mullite tube as well as other stainless steel components. Modifications and improvements are also being planned for the gas-purification and vacuum system.

#### Boiling Point Experiments

Figure 2 represents the boiling point apparatus which has been assembled for use in this investigation. It incorporates a differential thermocouple as a sensing element and can be used for determinations at either constant pressure or constant temperature. Essential details of this apparatus are two identical tubes placed symmetrically within a furnace. One of these contains potassium and the other an inert reference material, aluminum oxide.

For operation, a temperature is selected at which it is desired to determine the vapor pressure, and the manostat is set to control the system pressure at a pressure considerably higher than the vapor pressure is suspected to be. Once the system is in thermal equilibrium at the desired temperature the differential thermocouple would record a zero value. The system pressure is then slowly reduced. As long as the system pressure remains greater than the vapor pressure, vaporization and condensation rates in the vicinity of the sample would be essentially equal and no heat effect would be detected. However, as soon as the system pressure becomes slightly less than the vapor pressure, potassium would vaporize from the sample and condense at a distance. The consequent heat effect would show an immediate response in the differential thermocouple. The pressure at which this occurs is then recorded. Past experience indicates that a decrease of system pressure below vapor pressure of 0.3 per cent is sufficient to give rise to a detectable heat effect.

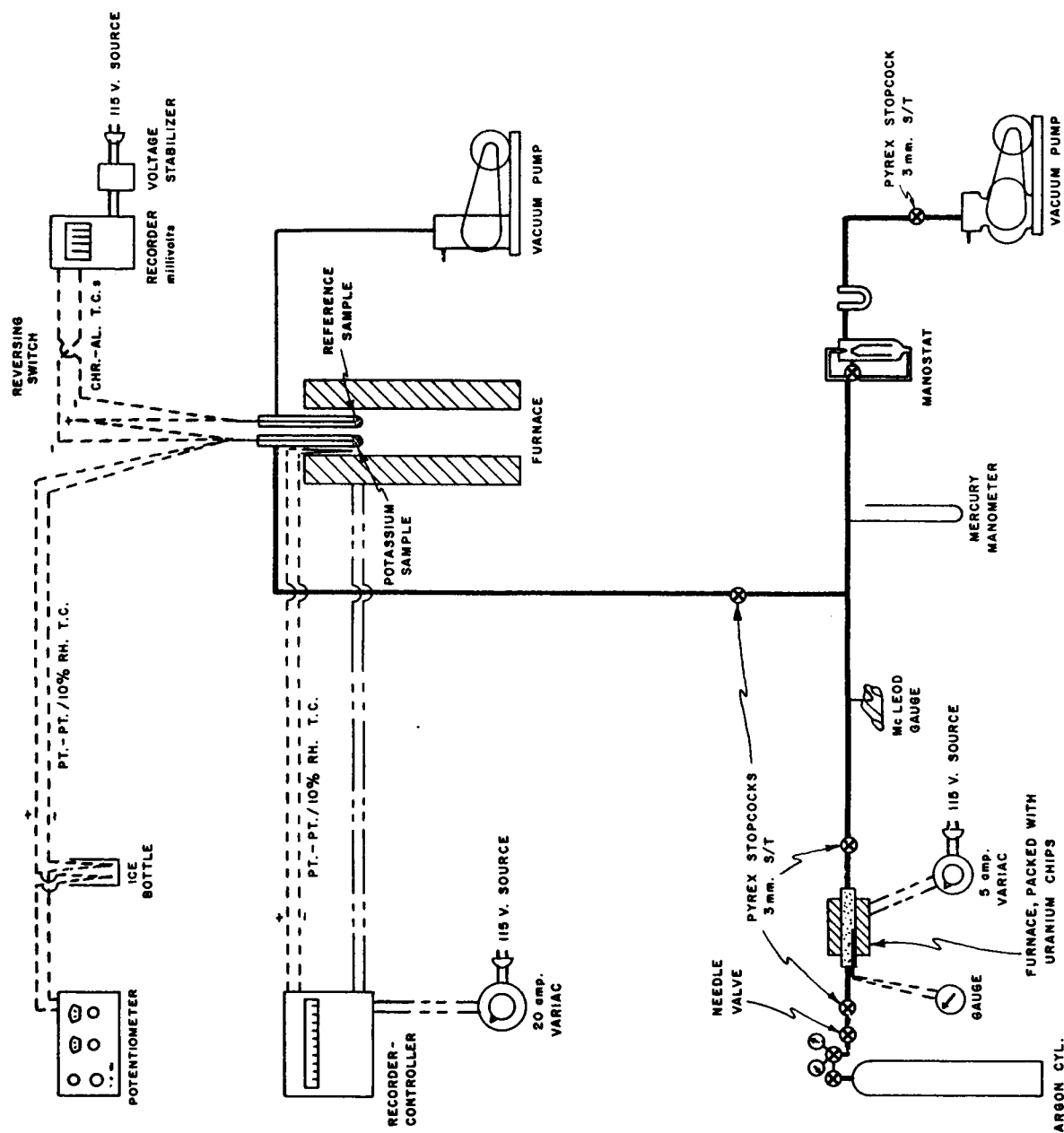


FIGURE 2. DIAGRAM OF BOILING POINT VAPOR PRESSURE APPARATUS

This apparatus was operated over a temperature range from 966 F (519 C) to 1432 F (789 C). The data obtained are summarized in Table 1. A least-squares fit to these data leads to the equation

$$\log P = - \frac{4330}{T} + 7.08$$

where T is in degrees K and P in mm Hg. From this equation the normal boiling point would be predicted as 1030 K. This compares to a value of 1033 K reported by Heycock and Lamplough<sup>(1)\*</sup> and by Fiock and Rodebush<sup>(2)</sup>. Makansi et al.<sup>(3)</sup> have reported 1027 K for the normal boiling point of potassium. The above equation (and the data) corresponds very closely to that of Makansi et al.<sup>(3)</sup> but differs widely from the results recently published by Grachev and Kirillov<sup>(4)</sup>. These latter results would lead to the prediction of 1068 K as the normal boiling point.

Estimates of accuracy indicate that the preliminary experiments reported in Table 1 may be in error by as much as about  $\pm 6$  C but that future results may be in error by less than  $\pm 1$  C. Thus, it is suggested that these preliminary results be used with caution until further, more accurate, experiments are made for verification.

TABLE 1. PRELIMINARY VAPOR PRESSURE  
DATA FOR POTASSIUM

Temperature		Pressure, mm Hg
C	K	
519	792	41
543	816	60
575	848	95
599	872	132
631	904	200
692	965	400
732	1005	598
750	1023	711
763	1036	800
789	1062	1005

\* See "REFERENCES" section.

MEASUREMENT OF LIQUID SPECIFIC HEAT\*

The specific heat of liquid potassium is to be measured up to 2100 F. In the measurement of specific heat, the specimen, encapsulated in a helium atmosphere, is dropped at a number of temperatures over the temperature range to be covered. An enthalpy (total heat content per pound between the specified temperature and 32 F) versus temperature curve is plotted, and slopes of this curve measured at interpolated temperatures give specific heats at these temperatures. An ice calorimeter is to be used for the enthalpy measurements.

The ice calorimeter has been described by Ginnings and Corruccini<sup>(5)</sup> and Deem and Lucks<sup>(6)</sup>. In the ice calorimeter, heat from the specimen melts ice that is in equilibrium with water in a closed system. The resulting volume change is determined by means of mercury which makes up the volume change. The ratio of heat input to the mass of mercury making up the volume change is a constant which is used as a calibration factor to obtain heat inputs to the calorimeter. There is no temperature change in the calorimeter since all heat transfer occurs at the ice point.

A stainless steel ice calorimeter will be used for the enthalpy measurements. The assembly is shown schematically in Figure 3. Not shown is a large Pyrex jar in which the calorimeter assembly is immersed in a mixture of ice and water.

The calorimeter consists of a double-walled vessel with dry CO<sub>2</sub> gas between the walls. The outer vessel, A, contains a mercury reservoir, B, which holds more mercury than is displaced during the freezing or melting of an ice mantle. The purpose of this reservoir is to have an adequate supply of mercury at the ice point to prevent introducing heat with reference to the ice point temperature existing in the calorimeter. Mercury is introduced into the reservoir from the external mercury accounting system through 1/8-inch-diameter stainless steel tube, C, passing down through the external ice and water bath. Similar tubing extends from the mercury reservoir to the calorimeter chamber.

The inner vessel, D, is the calorimeter chamber. It is filled with outgassed distilled water with about 3/4 inch of mercury in the bottom. The filling by water is done through a stainless steel tube, E, fitted with a special blunt-taper stainless steel needle valve. The vessel is evacuated and outgassed water introduced. A low-wattage resistance heater is wound around the inner vessel and is used to melt the outer part of the ice mantle should it touch the metal wall.

A stainless steel specimen-dropping tube, F, extends down through the tops of the outer and inner vessels. The tube is machined to have a 1/32-inch-thick wall everywhere except for two flanges to which are welded the tops of the two vessels.

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\*Presented by Herbert W. Deem

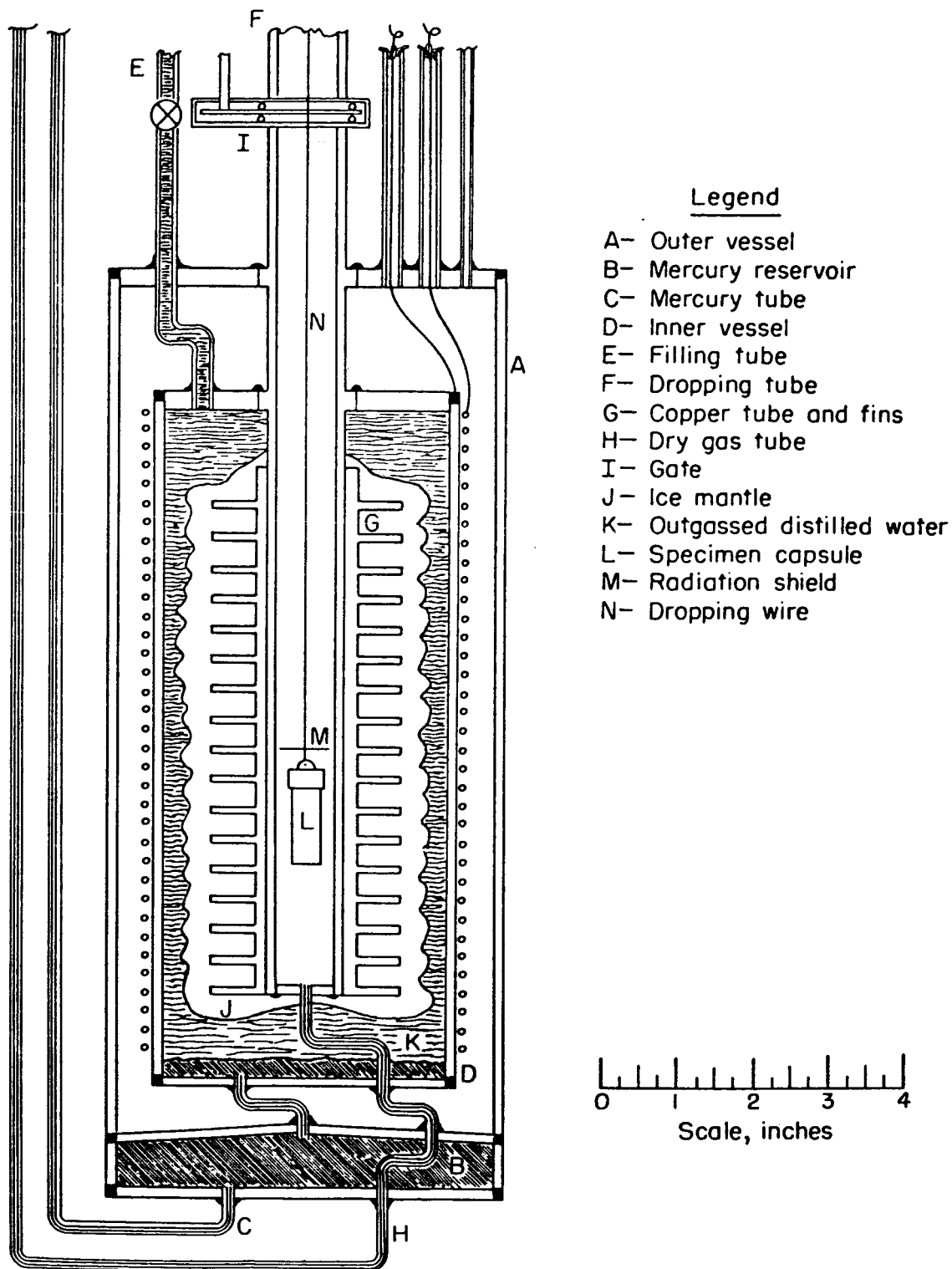


FIGURE 3. STAINLESS STEEL ICE CALORIMETER

Copper, because of its high thermal diffusivity, is used for the fins and tube around which the ice mantle is frozen. The fins and tube, G, shown in Figure 3 are machined from one piece of copper bar and are tinned to prevent attack by water. It is noted that the copper fin assembly does not extend to the full height of the calorimeter chamber. This is to reduce the chance of the ice mantle freezing against the ends of the chamber.

Provision is made by tube, H, to introduce argon into the bottom of the dropping tube. This gas, carefully dried and introduced at a low rate, reduces the entry of moisture into the calorimeter and also protects the capsule and dropping wire from oxidation.

A gate, I, is placed in the dropping tube to reduce heat transfer by radiation down the drop tube from the furnace. This gate is opened momentarily at a drop and then closed. A notch in the gate allows it to close with the dropping wire in place. Radiation losses from the capsule in the calorimeter in the direction of the gate are reduced by the use of a thin platinum radiation shield, M, attached to the supporting wire just above the capsule.

A gas-purification system for the argon has been assembled to protect the specimen capsule L from oxidation at high temperatures. The purification train includes a chemical drying agent, a cold trap, copper turnings at 1475 F, and uranium turnings at 1475 F. A gastight drop tube for the furnace has been assembled. Other related equipment including constant-voltage power supply, analytical balance, weights and potentiometer have been checked.

The vapor pressure of potassium at 2100 F should be about 300 psi. It has been calculated that a capsule (of welded design) made of Nb-1Zr and having a 1/64-inch wall thickness will contain approximately 840 psi. This wall thickness should, therefore, be sufficient for measurement to 2100 F.

The apparatus, except for specimen capsule, is ready for specific heat measurements of liquid potassium. Fabrication of the specimen capsule will follow some preliminary experiments to determine the compatibility of liquid potassium and Nb-1Zr under the conditions of the specific heat measurements. It is felt that this step is necessary to avoid possible loss of time and equipment. Specific heat measurements will be started after satisfactory results are obtained on the preliminary compatibility experiments.

#### MEASUREMENT OF LIQUID THERMAL CONDUCTIVITY\*

The thermal conductivity of liquid potassium is to be measured to 2100 F. Two methods, both involving steady-state comparative techniques, have been considered.

One method involves measurements with several specimen thicknesses at a given mean specimen temperature and will be referred to as the variable-gap method. The method has been described by Sakiadis and Coates(7) and

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\*Presented by Herbert W. Deem

Lucks and Deem<sup>(8)</sup>. Figure 4 is a schematic sketch of a variable-gap apparatus. The method, in principle, is to measure the total thermal resistance of a specimen at a given mean temperature with several different thicknesses of specimen, which varies with specimen thickness and the fixed thermal resistances such as that at the specimen-container interfaces. The thermal conductivity of the specimen is proportional to the reciprocal of the change in total thermal resistance and is independent of the fixed thermal resistances.

The second method considered is a steady-state longitudinal-heat-flow method and yields thermal conductivity values at several mean temperatures for each thermal equilibrium. A method of this general type has been described by Lucks and Deem<sup>(9)</sup>. Figure 5 is a schematic sketch of a longitudinal-heat-flow apparatus for liquids. In brief, the method consists of heating one end of a specimen, measuring the temperature gradient along the specimen, and determining the rate of heat flow through the specimen by means of a metal standard of known thermal conductivity attached to the cold end of the specimen. Radial heat flow into, or away from, the specimen is minimized by thermal guarding.

Of these two methods considered for measuring the thermal conductivity of liquid potassium, the variable-gap method has several disadvantages which make it the less desirable method at this time. These are:

- (1) It is time-consuming as it requires a number of equilibria to obtain a thermal conductivity value at one mean temperature;
- (2) It will amplify any material-compatibility problem resulting from time-temperature effects.

For these reasons greater emphasis will be placed on detailing an apparatus of the longitudinal-heat-flow type for the thermal-conductivity measurements on liquid potassium.

#### MEASUREMENT OF VAPOR VISCOSITY\*

Data on the transport properties of potassium are required for the design of a high-temperature nuclear electric-generating system using potassium as a working fluid. No measurements of the viscosity of potassium vapor have been found in the literature. Therefore, it is the purpose of this part of the program to determine the viscosity of potassium vapor as a function of temperature from 900 to 2100 F.

The literature has been surveyed for viscosity measurement techniques which might be applied to potassium vapor. It appears that the capillary-flow principle would be most easily utilized for the design of a viscometer suitable for this system. In this method, the volume,  $V$ , of fluid flowing through a capillary tube of radius  $a$ , in unit time under pressure

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\*Presented by Elton H. Hall



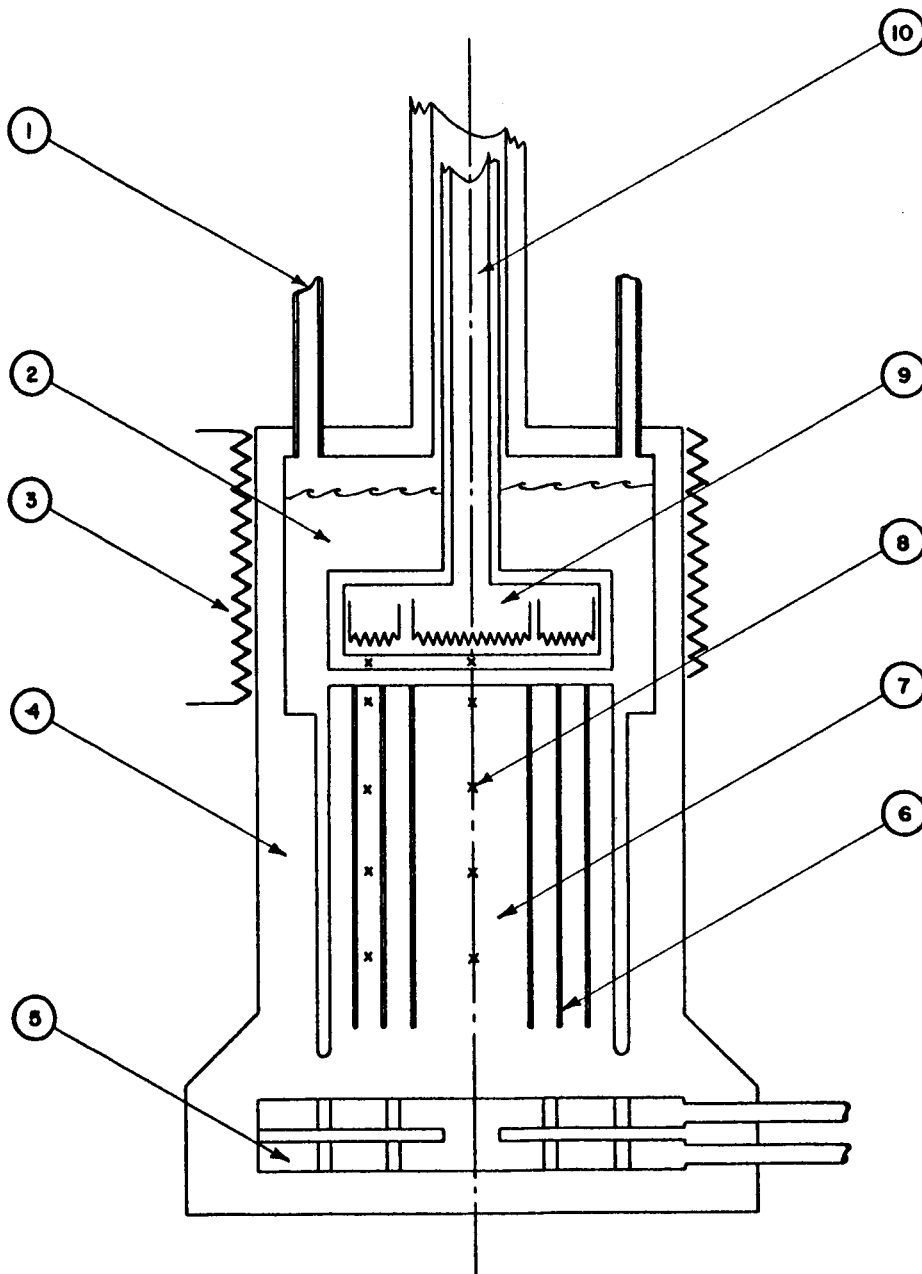


FIGURE 4. SCHEMATIC SKETCH OF VARIABLE-GAP  
THERMAL-CONDUCTIVITY APPARATUS

- |                           |   |
|---------------------------|---|
| 1. Specimen filling tubes | 7. Heat flow meter  |
| 2. Specimen               | 8. Thermocouples  |
| 3. Specimen guard heater  | 9. Variable-gap and heater assembly   |
| 4. Pressure container     | 10. Connections to power supply, thermocouples, gap-measuring device, and high pressure manifold. |
| 5. Sink                   |   |
| 6. Heat flow meter guards |   |

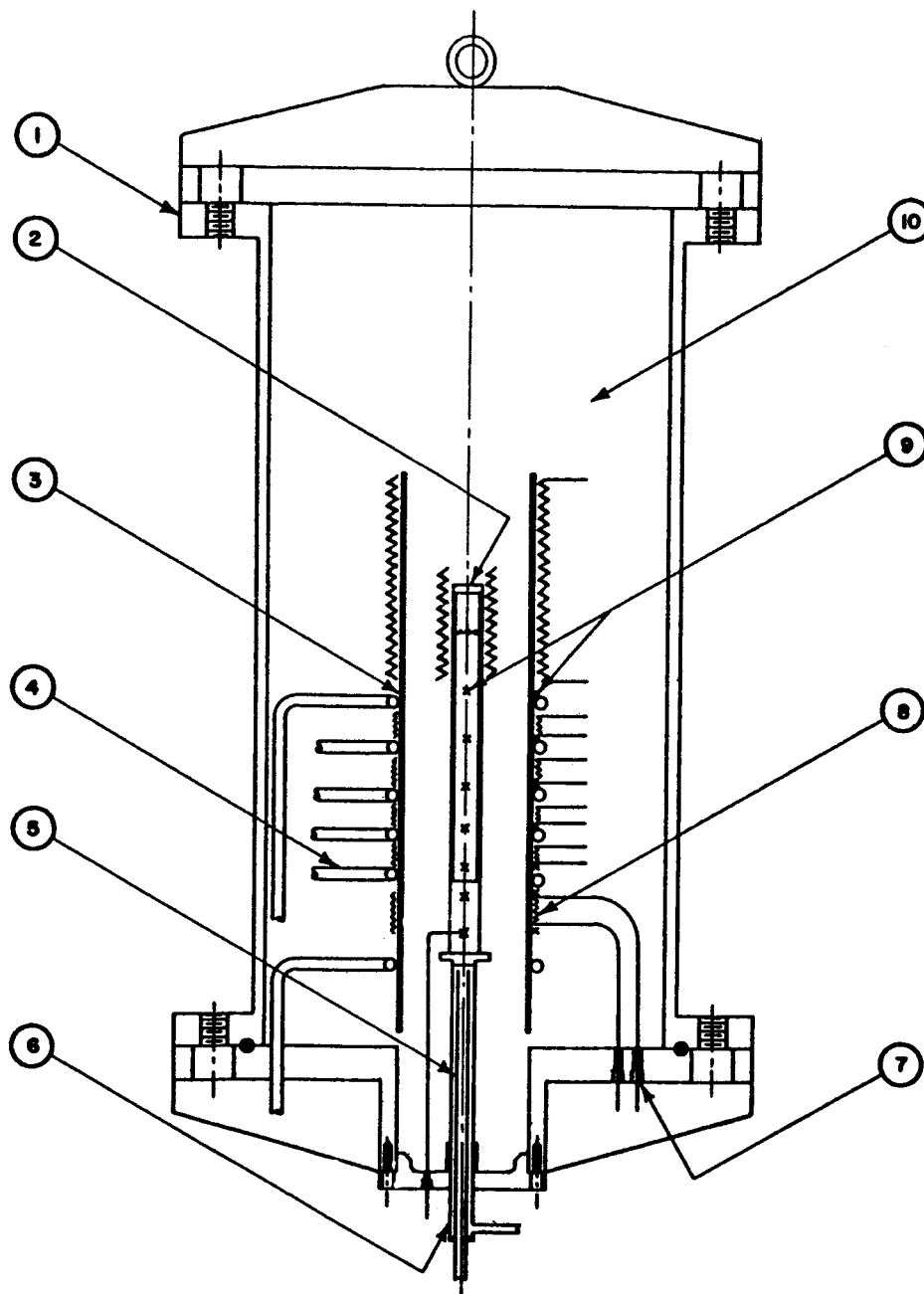


FIGURE 5. SCHEMATIC SKETCH OF THE LIQUID  
THERMAL-CONDUCTIVITY APPARATUS

- |                           |   |
|---------------------------|---|
| 1. Pressure container     | 6. Sink inlet and outlet                                |
| 2. Specimen assembly      | 7. Hermetic seals for heater<br>leads and thermocouples |
| 3. Guard assembly         | 8. Heaters  |
| 4. Guard cooling coils    | 9. Thermocouples  |
| 5. Specimen sink assembly | 10. Insulation  |

gradient -  $\frac{dP}{dL}$  is observed. The fundamental Poiseuille equation,

$$V = \frac{\pi a^4}{8\mu} - \frac{dP}{dL} ,$$

is used to calculate the viscosity,  $\mu$ , from the measured quantities.

The actual design of a viscometer based on this principle has been deferred until the apparatus for measurement of liquid viscosity apparatus has been designed.

### MEASUREMENT OF LIQUID VISCOSITY\*

A review of the literature was made in order to evaluate the several techniques for measuring liquid viscosity. The oscillating-cylinder method was selected as the one most readily adaptable to potassium liquid. A closed hollow cylinder containing the liquid is suspended from a torsion wire and is permitted to oscillate about the axis of the suspension. Observation of the damping of the oscillation caused by the liquid permits calculation of the viscosity.

The features recommending this technique are:

- (1) The highly reactive potassium is sealed inside a small cylinder, thus protecting it from the external atmosphere throughout the entire series of measurements,
- (2) The potassium is in contact with a limited area of container material,
- (3) The method can be made to yield absolute values of viscosity by mathematical treatment of the data or, more simply, the viscometer may be calibrated by the use of liquids of known viscosity.

The principle components of an oscillating-cylinder viscometer are illustrated in Figure 6. The diagram does not show details of construction, as a few are not yet finalized.

The cylindrical crucible containing the potassium is suspended within an electric furnace. The suspension consists of a torsion wire, an angular deflection indicator (not shown), and a stiff suspension rod. The inertia bar is used to adjust the period of oscillation to a convenient value. In addition, by adding weights of known moment of inertia to the bar and observing the period of oscillation, the moment of inertia of the entire system may be calculated.

The furnace will be wound noninductively to reduce the magnetic field produced by the heater current, thus minimizing the magnetic damping

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\*Presented by Elton H. Hall

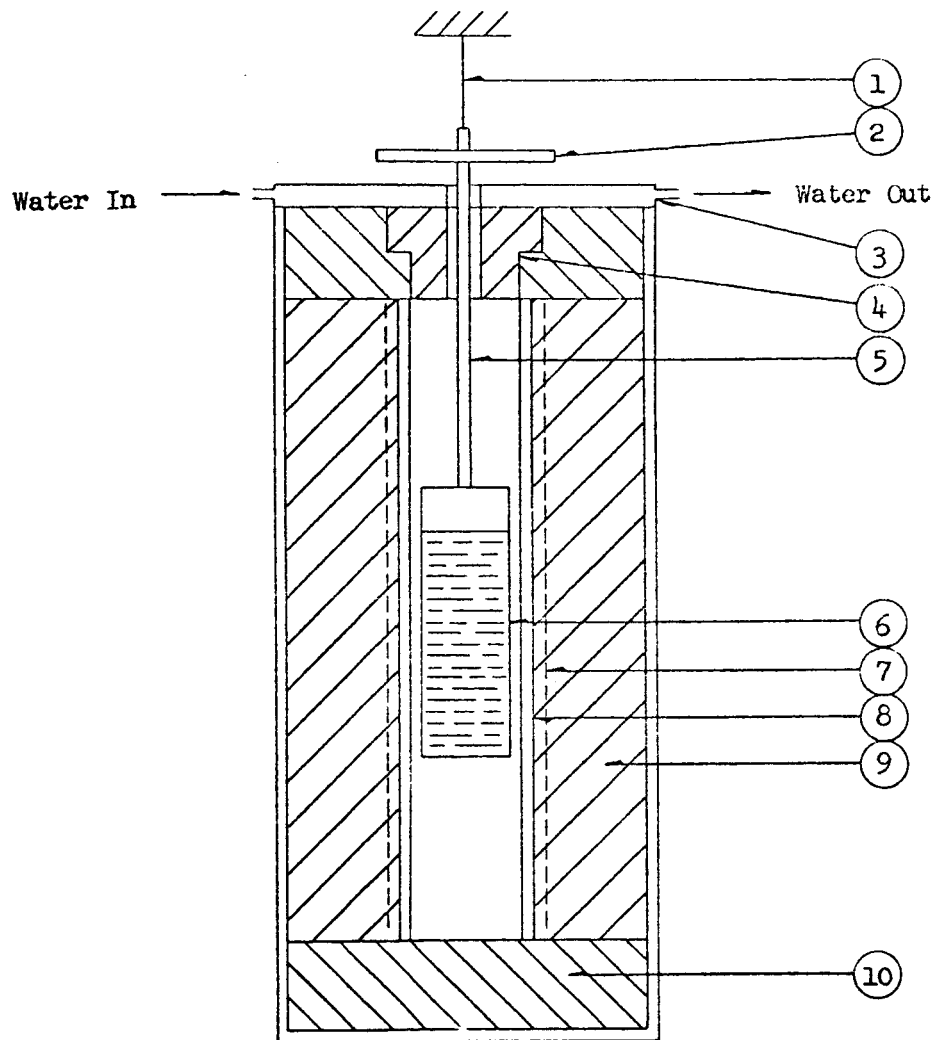


FIGURE 6 . DIAGRAM OF VISCOSITY MEASURING APPARATUS

- |                              |                       |
|------------------------------|-----------------------|
| 1. Suspension wire           | 6. Crucible           |
| 2. Inertia bar               | 7. Electric heater    |
| 3. Removable top cooler      | 8. Liner              |
| 4. Removable refractory plug | 9. Refractory packing |
| 5. Suspension rod            | 10. Refractory base   |

of the oscillating cylinder. The extent of magnetic damping will be determined before measurements are begun. The cooler plate on the top of the furnace serves to prevent the torsion wire from heating.

The angular deflection detector will employ a commercial instrument called a Metrisite manufactured by Brush Instruments, Cleveland, Ohio. The Metrisite is an electromechanical position-sensing device having a very low reaction force. An electrical output is produced which is proportional to the position of the sensing element.

A photograph of the preliminary assembly of the suspension system is shown in Figure 7. The vacuum chamber and quartz envelope enclosing the cell have been removed. The torque-head assembly permits the upper end of the torsion wire to be rotated through a small angle in order to induce oscillations which are essentially free of transverse vibrations. The solenoid shown can be used to rotate the torque head when the system is evacuated. The double pin vise connects the torsion wire to the rigid cell-support members. A lamp scale and mirror (not shown) will also be incorporated for use if the Metrisite sensitivity is not adequate. The locking chuck is used to hold the support rod rigidly during assembly.

The cylinder shown in the photograph is made of copper and is to be used during a check run with water as the liquid to verify the suitability of the dimension of the cylinder. A similar cell will then be machined from Nb-1Zr alloy to contain the potassium

#### PRESSURE-VOLUME-TEMPERATURE MEASUREMENTS\*

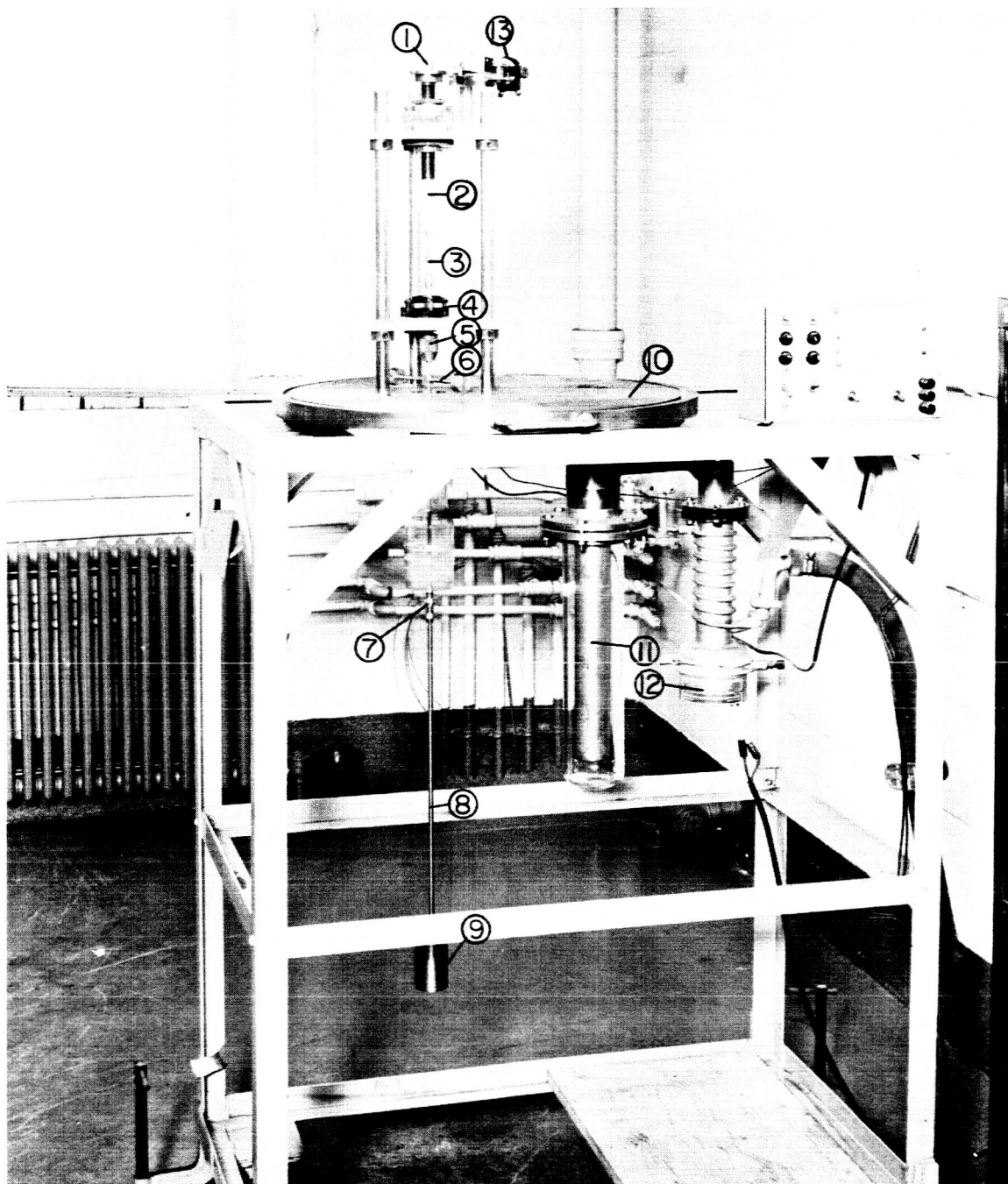
As part of the program on engineering properties of potassium, pressure-volume-temperature data are to be obtained and thermodynamic properties calculated from these data. Work on this problem began late in March with a study of various systems and techniques for these measurements.

Two methods have been explored by which the desired data can be obtained; these are constant-pressure and constant-volume systems. The constant pressure system of Kay and Rambosek<sup>(10)</sup> consists of a glass capillary tube in which the material to be investigated is confined by means of a mercury seal. Volume is measured by means of a cathetometer, and pressure determined by use of a dead-weight gage. In this system a constant pressure can be maintained and the volume as a function of temperature recorded.

In the constant-volume system, pressure as a function of temperature is recorded. A number of methods of measuring the pressure in constant-volume systems have been developed. Most systems involve the balancing of pressures on a diaphragm. The null position of the diaphragm can be determined by capacitance as is described by Wiederhorn et al.<sup>(11)</sup>, or by electrical contact as described by White and Hilsenrath<sup>(12)</sup>.

---

\*Presented by William H. Mink



N79049

- |                            |                                 |
|----------------------------|---------------------------------|
| 1. Torque head             | 8. Support tube                 |
| 2. Torsion wire            | 9. Copper sample cylinder       |
| 3. Double pin vise         | 10. Vacuum-can base plate       |
| 4. Metrisite               | 11. Liquid nitrogen-cooled trap |
| 5. Locking chuck           | 12. Oil diffusion pump          |
| 6. Inertia bar and weights | 13. Solenoid                    |
| 7. Lower pin vise          |                                 |

FIGURE 7. OSCILLATING-CYLINDER VISCOMETER

For the present measurements the constant-volume system has been selected because of the difficulty of obtaining the sealing liquid required for the constant pressure system. A bomb enclosed in a furnace will be connected to a potassium filling and pressure-measuring system through a capillary. A high temperature gradient along the capillary will permit location of the potassium liquid-vapor interface so that accurate volumes can be determined. Pressure measurements will be made using a sensitive pressure gage separated from the liquid potassium system by means of a diaphragm.

E-1549

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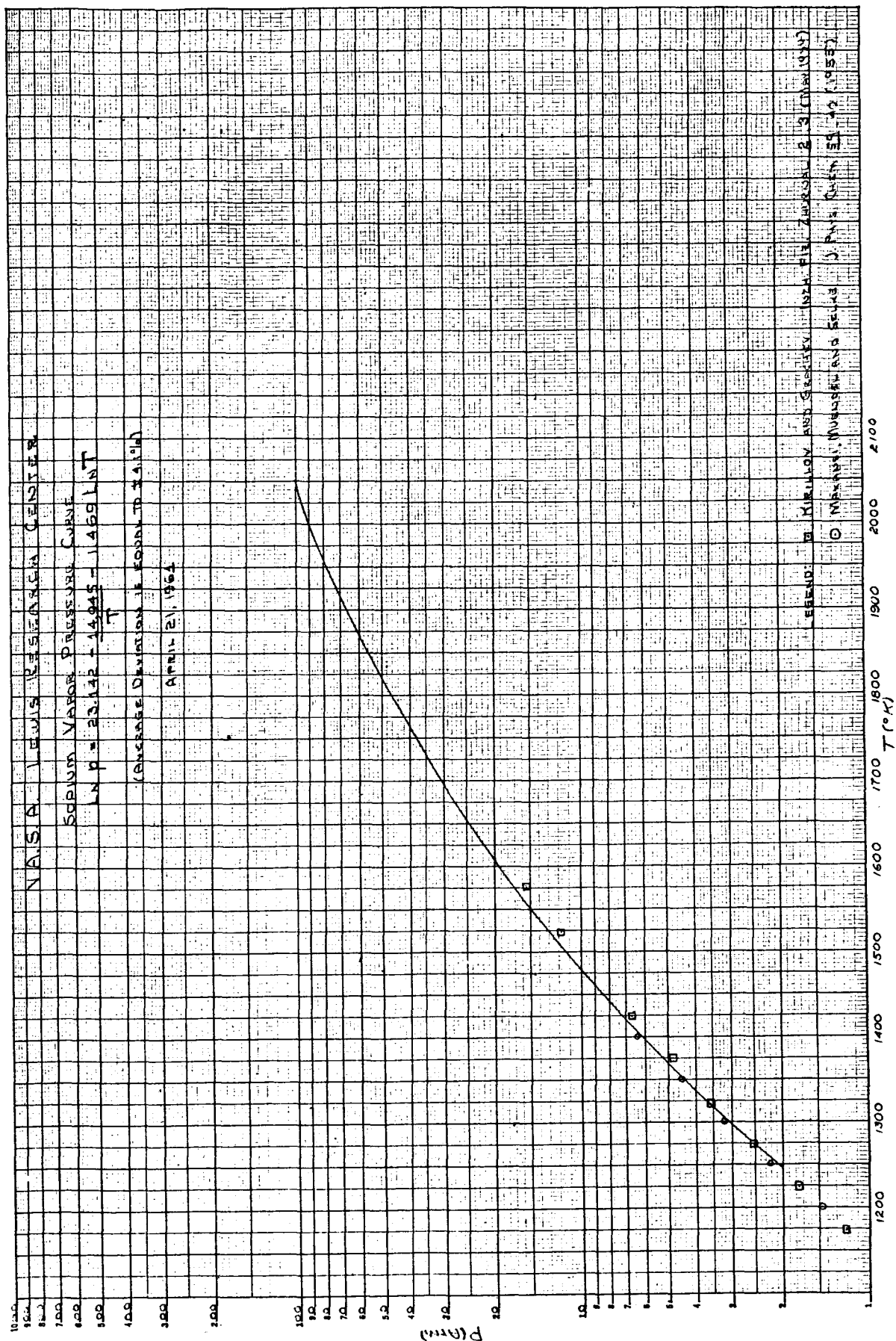


NASA-LEWIS RESEARCH CENTER

Critical Properties of the Alkali Metals

Results to date on sodium, presented by Dr. Louis Rosenblum.

E-1549



## SUMMARY OF NRL SODIUM PROGRAM

JACK P. STONE

Presented at NASA Conference on Properties of Alkali Metals

Battelle Memorial Institute

24 April 1961

E-1549

The program at NRL is designed to measure physical and thermal properties of sodium to 2500°F. The program is divided into two phases. The first phase includes determinations of: (1) specific heat of the liquid, (2) density of the liquid, (3) vapor pressure, (4) PVT data, and (5) equilibrium solubility of Cb and Zr in the liquid. In the second phase, measurements will be made of: (1) thermal conductivity of the liquid, (2) viscosity of the liquid, (3) viscosity of the vapor, and (4) transport solubility of Cb and Zr in boiling and condensing sodium. The assembly and testing of apparatus for the first-phase measurements are in progress. The design and methods to be used in the second-phase measurements are to be firmed by August 1961.

The first phase which includes the measurements necessary for construction of temperature-entropy and enthalpy-entropy diagrams is the subject of this presentation.

An alloy, Cb-1%Zr, was selected as the container material for sodium in these measurements. To protect the alloy, welding grade argon which has been passed through a heated column of titanium sponge and a column of molecular sieve is used. Also the apparatuses will be surrounded with Zr foil and Cb chips for further protection. Trace amounts of oxygen and moisture in the purified gas stream will be monitored.

A study has been in progress for the purpose of selecting a thermocouple combination suitable for use in the program. The combinations investigated thus far are: (Pt-Pt,10%Rh) (Pt-Pt,13%Rh) (Pt,1%Rh-Pt,13%Rh) (Pt-Rh) (Rh-Pt,20%Rh) (Ir-Ir,50%Rh) (Pt,6%Rh-Pt,30%Rh). In general these combinations are reasonably stable in air at 1400°C for 250 hours, and shifts in e.m.f. amount to less than 1°C for constant immersion lengths. In argon, however, shifts of some of these couples amount to as much as 50°C for the same conditions of temperature, time,

and immersion. Investigations to date indicate that these large shifts depend on purity of insulation as well as temperature, time, and immersion. At present the most promising combinations are (Ir-Ir, 50%, Rh) and (Pt, 6% Rh-Pt, 30% Rh) when used with high purity insulation such as McDanel's alumina AP-35 or Norton's RA 7232. Tests now in progress indicate that either of these couple combinations should be sufficiently accurate when used in argon at 1400°C for 250 hours.

The same general furnace design is used for each of the measurements except for specific heat. Pressure shells made from a 5-foot length of 12-inch steel pipe with flanges welded on either end house the furnaces. Mounted in the center of each shell is a 36-inch alumina core on which three molybdenum heaters are wound. The annular space between the core and shell is filled with zirconia bubble insulation. The interior of each upright furnace is divided into an inner and outer chamber by a closed-end quartz or morganite tube extending into the bore of the furnace core past the isothermal zone. These tubes are suspended from a flange arrangement which effects a seal between the two chambers and permits the Cb alloy apparatuses with couples, heat shields, and gettering shrouds to be positioned in the tubes. The furnaces are equipped so that each chamber may be evacuated individually; and purified argon pressure may be adjusted, either up or down, at controlled rates without a transfer of gas from the outer to the inner chamber or a significant pressure differential between the two chambers. For measuring pressures, calibrated bourdon gages and manometers are used.

The PVT or null-point apparatus is a closed Cb alloy pot with an inside diameter of about 1-3/8 inches and a height of about 2-1/3 inches. A plain diaphragm, backed on either side, is welded at the top of the container. A follower is placed on the diaphragm, and a projection of the follower is used to indicate the position of the diaphragm relative to projections from the top of the vessel. These projections will be observed optically through a sight port in the furnace to determine the position of the diaphragm. A vile containing a known weight of sodium will be placed in the pot through a tube at the bottom, and the tube will be pinched and welded after evacuation of the pot. The pot will be brought to equilibrium temperatures in the furnace, and argon pressures in the furnace will be adjusted equal to the sodium pressure in the pot by positioning the diaphragm at its null position. The furnace pressure is then a measure of the sodium pressure in the pot. An apparatus is also being made in which the null position of the diaphragm will be determined electrically.

Density of liquid sodium will be measured pointwise in an apparatus of the pycnometer type. A pot of known volume will be filled with sodium, and the filling tube will be cut to a desired length in an inert gas chamber. An overflow vessel will be welded in place around the filling tube, and the apparatus evacuated and closed. The apparatus is then brought to a maximum equilibrium temperature in a pressurized furnace, cooled, and removed. After removal of the overflow vessel, the amount of sodium in the pot of known volume will be determined by weight and by chemical titration.

Vapor pressure of the sodium will be measured by a direct boiling method with an apparatus similar to that used by Makansi, et al (J. Phys. Chem. 59, 40, 1955) with the addition that higher pressures will be measured with calibrated bourdon gages.

Specific heat of liquid sodium will be measured in a copper-block calorimeter which has been in use for several years. This calorimeter is a modified version of Southard's apparatus. A container of sodium is dropped from a furnace at a known temperature into the calorimeter, and the heat evolved from the furnace temperature to the operating temperature of the calorimeter is measured. The heat capacity of the sodium is then derived from the heat content measurements by the usual methods. In order to use the existing calorimeter without redesign, protection of the Cb-1%Zr alloy was attempted with a flow of purified argon without success. While the system is being modified for better protection of the alloy, measurements are being continued with an inconel container; and inconel will probably be used to 1200°C.

The solubility study of Cb and Zr (from Cb-1%Zr alloy) in sodium liquid was described by Mr. T. A. Kovacina at the NASA-AEC Liquid-Metal Corrosion Meeting held in Washington in December 1960 (NASA TN D-769, pg. 73).

With the reservation that changes will be made as indicated by the character of the data, the quantities necessary to construct a Mollier diagram will be computed as follows: (1) Enthalpy and entropy of the liquid from specific heat; (2) The latent heat of vaporization and entropy of vaporization from the Clapeyron equation and vapor pressure; (3) Specific volume of the vapor from the PVT measurement; (4) Specific volume of the liquid from the density measurement; and (5) Enthalpy and entropy of superheated vapor from their relation to the change of volume with respect to temperature at constant pressure and heat of dimerization from PVT measurement.

THERMAL CONDUCTIVITY OF LITHIUM

H. W. Hoffman, J. W. Cooke

Oak Ridge National Laboratory

E-1549

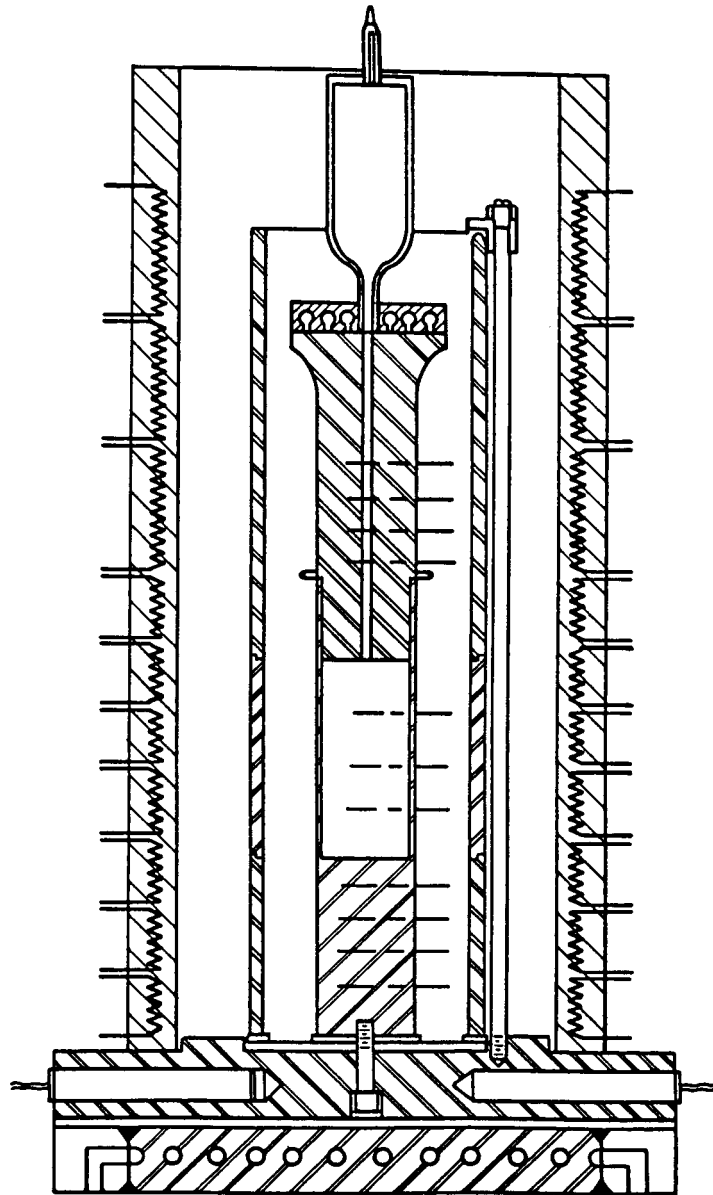
Temperature range: 600 to 1500°F

Apparatus: (1) Axial heat flow, comparison type (see Fig. 1).

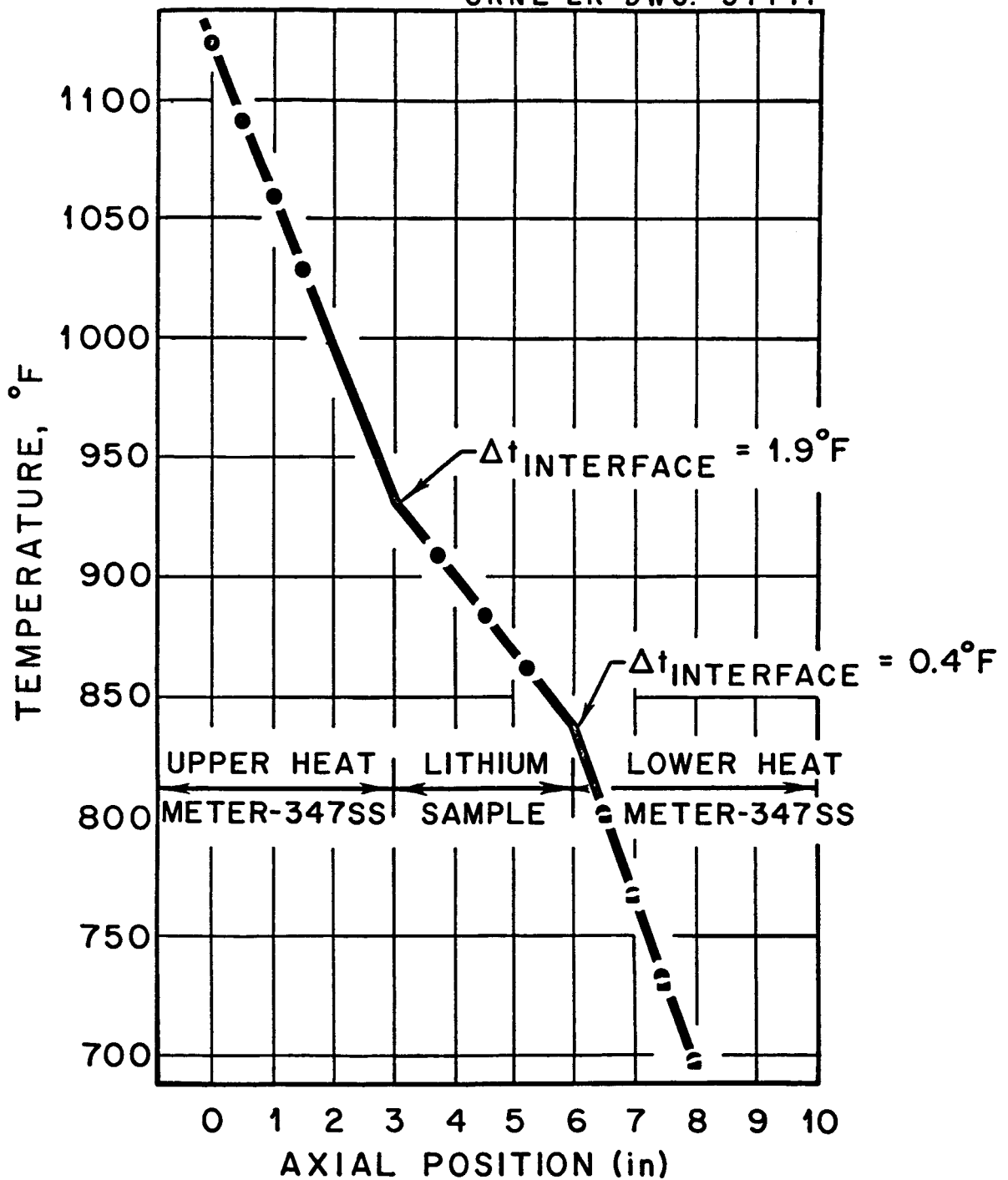
- (2) Thermal flux established by heat meters (type 347 stainless steel) located above and below lithium sample region.
- (3) Radial heat flow minimized by a coaxial guard tube in which longitudinal temperature gradient closely approximated that in test piece.
- (4) Axial heat flow generated by a disk heater at top of upper heat meter; a water-cooled copper plate served as heat sink.
- (5) Guard heating provided by a set of 10 individually controlled heaters located outside and coaxial with guard tube.
- (6) Test unit positioned within a furnace to control temperature level; vacuum environment.

- Results:
- (1) Axial-temperature profiles (typical shown in Fig. 2) indicated small interfacial resistance and a less than 3% deviation between heat flows calculated from upper and lower heat meters.
  - (2) Radial heat loss estimated to be less than 1% of axial heat flow in sample region.
  - (3) Thermal conductivity ranged from 27 Btu/hr·ft·°F at 750°F to 29 Btu/hr·ft·°F at 1500°F (see Fig. 3).

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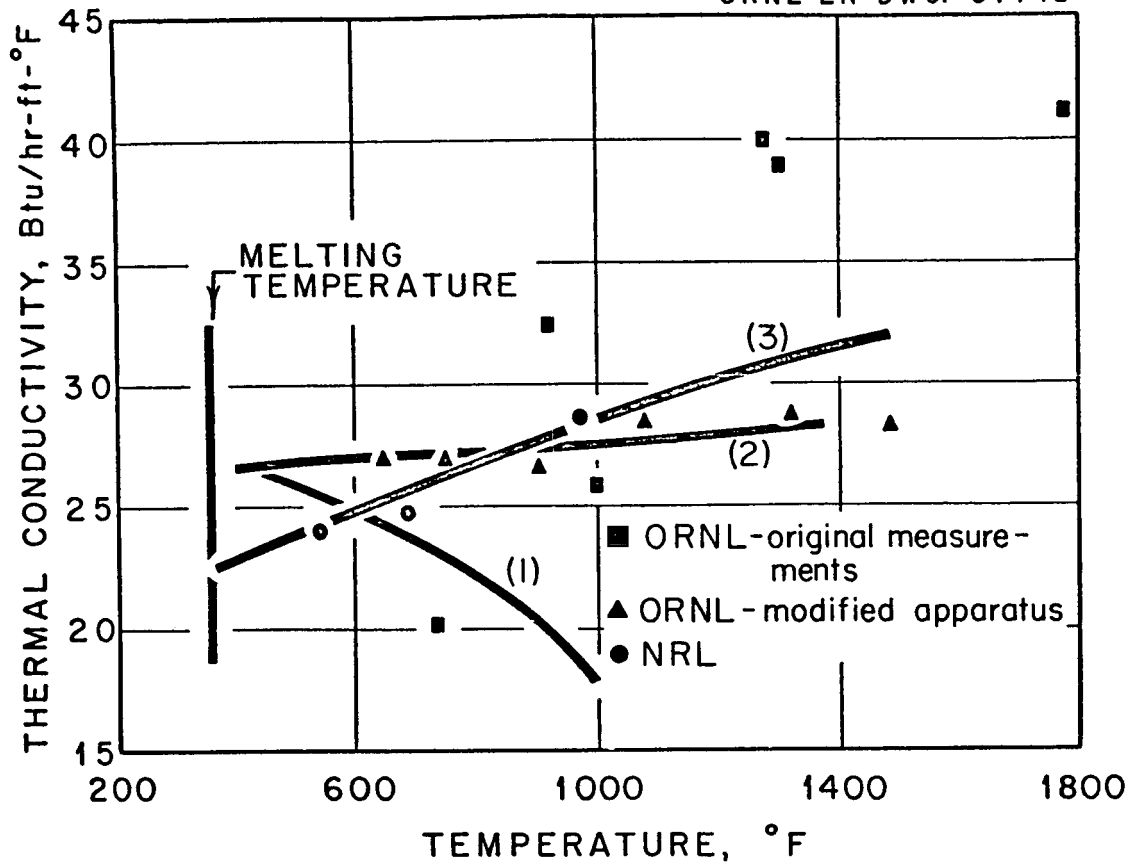


LITHIUM THERMAL CONDUCTIVITY APPARATUS

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TYPICAL AXIAL TEMPERATURE  
PROFILE, LITHIUM THERMAL  
CONDUCTIVITY STUDY



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ORNL-LR-DWG. 57712

## THERMAL CONDUCTIVITY OF LITHIUM

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# *Aerojet-General* NUCLEONICS

A SUBSIDIARY OF AEROJET-GENERAL CORPORATION

P.O. BOX 77, SAN RAMON, CALIFORNIA (NEAR SAN FRANCISCO) TWX NUMBER: DANVILLE 1316  
TELEPHONE VERNON 7-5311 • CABLE ADDRESS: AGNU

May 5, 1961

E-1549

Mr. A. W. Lemmon, Jr.  
Battelle Memorial Institute  
505 King Avenue  
Columbus, Ohio

Dear Mr. Lemmon:


The attached summary briefly describes the liquid metals work being performed at Aerojet-General Nucleonics. The Metallurgy Department is conducting the Rubidium and Cesium Programs under contract to the U.S.A.E.C. Mr. David E. Deutsch is the Project Manager and Mr. Peter F. Young is the Project Engineer for both programs. These two programs are being carried out to develop basic system design data on the working fluids involved before systems using these fluids progress to the hardware stage. The program results, together with data already published concerning Na, NaK and K, will allow the best choice of working fluid for a specific turbo-generator system at the beginning of system design rather than delaying this decision until long after program initiation.

The SNAP VIII Mercury Program is conducted by the Engineering Division of AGN. Mr. John Payne is the Project Engineer. This work is a design parameter study of the power-conversion system for the existing SNAP VIII concept.

AGN extends an invitation to those with a technical interest in liquid metals technology, particularly the attendees of the BMI Liquid Metals Conference, to visit AGN at their convenience for discussions of our liquid metals work and inspection of our experimental facilities.

Very truly yours,

AEROJET-GENERAL NUCLEONICS

  
Ray W. Carpenter  
Metallurgical Engineer

RWC:br

LIQUID METALS WORK SUMMARY\*I. INTRODUCTION - AEROJET-GENERAL LIQUID METALS PROGRAM

## A. RUBIDIUM PROGRAM

The objective of this program (USAEC Contract AT(04-3)-251) is to test materials for compatibility with high temperature rubidium liquid and vapor under static and dynamic conditions and to determine experimentally some thermodynamic and physical properties of rubidium.

1. Static Corrosion Capsule Tests

The static corrosion tests will be conducted in a boiling re-fluxing test capsule developed at AGN. A cross-section view is shown in Figure 1. Design test conditions for the capsule are shown below.

Temperature of capsule wall	= 1800° F
Time Duration	= 500 hrs
Coolant in Coils	Water
Containment Vessel	Argon, purified through molecular sieve and zirconium chip furnace (1500°F)

A static capsule corrosion test run has been completed on dry hydrogen annealed type 316 stainless steel tubing, 0.5" O.D. X 0.049" wall thickness. The test sample contained 12.5 grams rubidium and was run for 50 hrs at 1550°F and 50 hrs at 1800°F. Estimated internal pressure in the test capsule was 192 psi at 1800°F, resulting in about 980 psi tube wall stress.

Very little attack was observed on the stainless steel. A small deposit of crystals found in the colder region is believed to have resulted from mass transfer; however, the crystals have not been identified at present. The surface of the steel is etched lightly just above the liquid-gas interface. Metallographic examination of this region showed slight intergranular attack. Corrosion effects were more pronounced in the vapor region than in the liquid region. The results of this test indicate that 316 stainless steel is adequate for containment of rubidium in short time exposures at 1200°F and low stress levels.

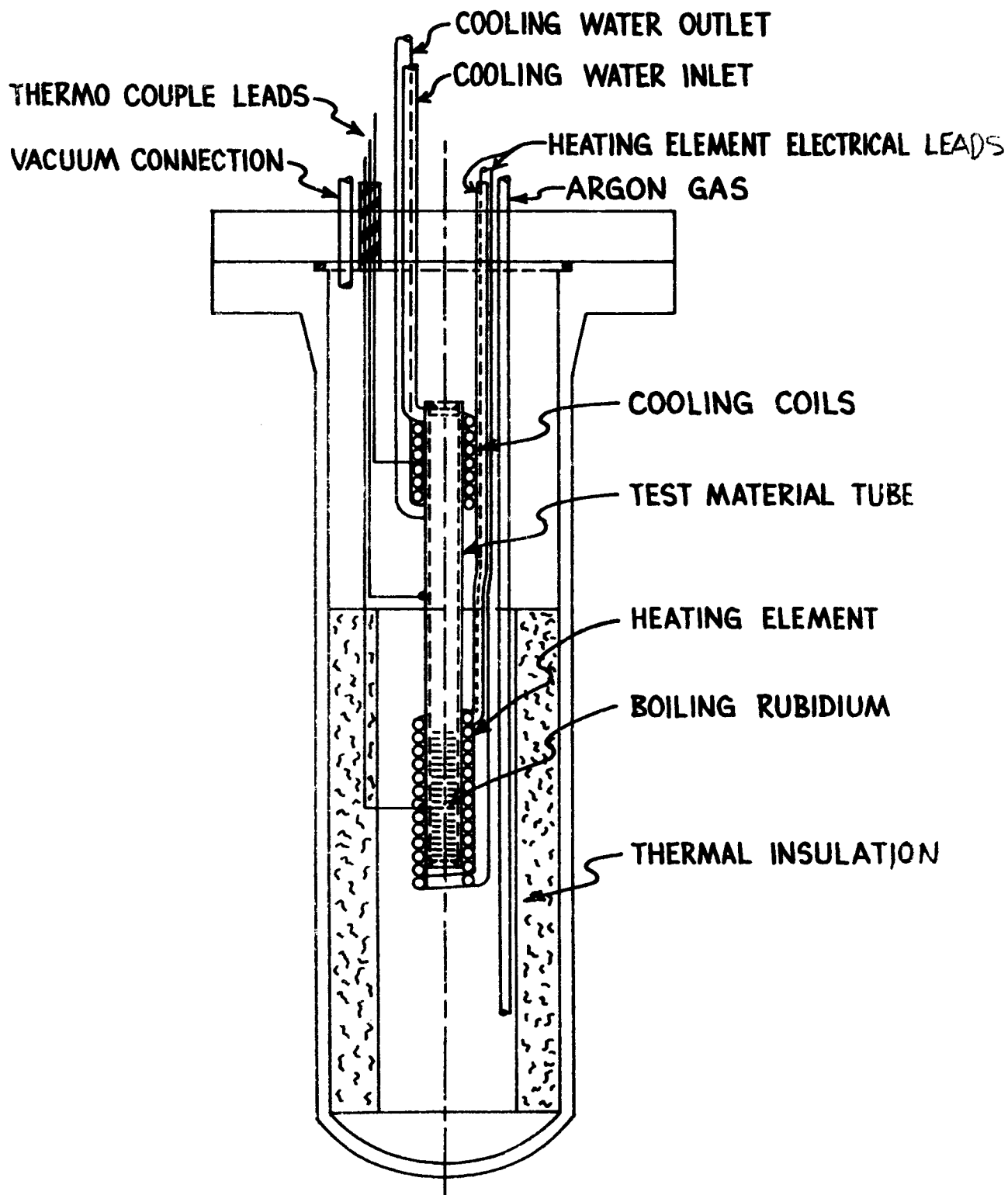
The successful operation of the 316 stainless steel capsule demonstrated the workability of this capsule design. A more extensive rubidium capsule corrosion test program is now being carried out for the following materials and conditions:

- a. Boiling-refluxing capsule tests using rubidium will determine corrosion effects.

---

\*Presented by Ray W. Carpenter

E-1549



**FIG. 1 BOILING RUBIDIUM TEST CAPSULE**

<u>Material Tested</u>	<u>Time, Approximate Hours</u>	<u>Temperature Range ° F</u>
Cb-1% Zr	1000	1400-2000
Mo-0.5% Ti	1000	1400-2000
A V Base Alloy	1000	1000-1200
A Ni Base Alloy	1000	1200-1800
such as Inconel X		
A Be Alloy	1000	1000-1600

b. Equilibrium solubilities as a function of temperature for the capsule materials in rubidium will be determined. Time of test is expected to be 50-100 hrs in the temperature range 1000° to 2000°F.

c. Mechanical property tests on the capsule materials after test to determine the effects of rubidium corrosion.

## 2. Loop Program

The loop will provide information on the design, control and instrumentation of boiling flowing liquid metal systems, the corrosive effects of boiling flowing rubidium, and the specific heat of rubidium. The temperature range of interest is 1000° to 1800°F.

The loop system is shown in Figure 2. It consists of three distinct parts or subassemblies: the rubidium or primary loop, the argon gas loop, and the water circulation loop.

The primary loop circulates the rubidium, heats it at one end and cools it at the other, and maintains a set pressure of argon gas on the flowing rubidium to control the boiling rate. The rubidium is heated by direct electrical resistance. The metal is circulated by an electromagnetic pump.. Pressure is maintained in the loop by balancing the argon gas pressure over the rubidium in the surge tank against the vapor pressure of the boiling rubidium at the operational temperature. The condenser-cooler provides a temperature differential in the circulating rubidium and simulates a space power system heat rejection radiator.

### a. Heater Design

The heating system is divided into two sections. The first heats the rubidium to a temperature at or near the maximum of 1900°F. The second (boiler) section provides additional heat to boil the liquid metal and raises the vapor quality to the desired value at the boiler outlet.

#### Heater Parameters:

Length	= 6.0 feet
Tubing size	= 0.25 in. O.D. X 0.150 in. I.D.
Max. Liquid Velocity	= 10 feet/sec
Max. heat input	= 32,500 Btu/hr or 103,000 Btu/hr/ft <sup>2</sup>
t <sub>max</sub>	= 1900°F
ΔP <sub>max</sub>	= 0.94 psi
Max. Vapor quality	= 0%

# INSTRUMENTATION AND CONTROL SYSTEM FOR BOILING OPERATIONAL RUBIDIUM INTERCIRCULATION SYSTEM

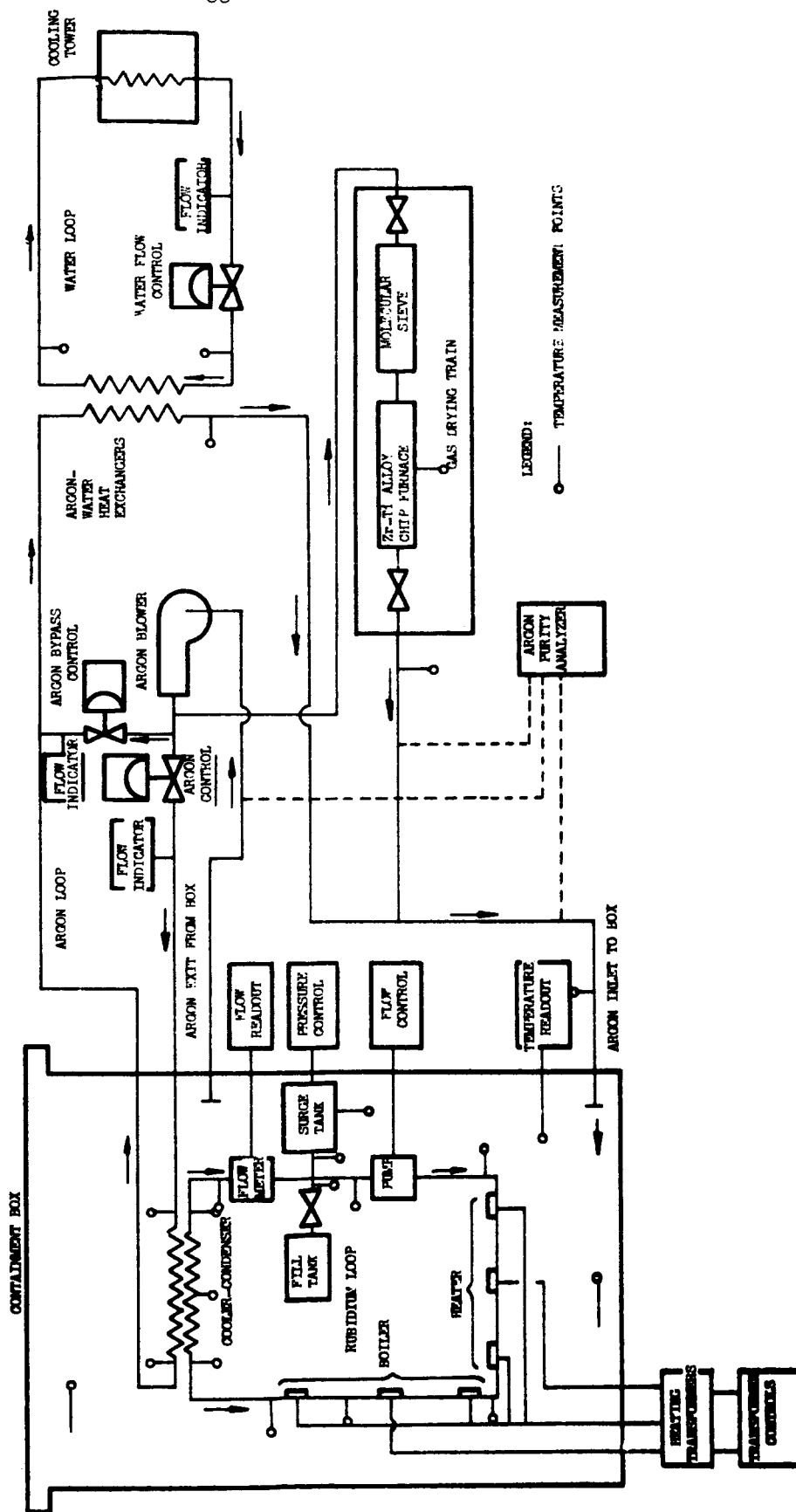


FIGURE 2

## Boiler Parameters:

Length	=	5.0 feet
Tubing size	=	0.5 in. O.D. X 0.400 in. I.D.
Max. Vapor Velocity	=	71 feet/sec
Max. heat input	=	61,200 Btu/hr or 89,000 Btu/hr/ft <sup>2</sup>
t <sub>max</sub>	=	1900°F
$\Delta P_{max}$	=	2.3 psi
Max. Vapor Quality	=	50%

The argon gas loop serves the double purpose of removing heat from the rubidium loop and of providing a protective atmosphere for the columbium loop in the environmental chamber. A large axial fan blows argon through the system. About 1 to 2% of the argon flow is continuously diverted through a purification train to remove O<sub>2</sub>, N<sub>2</sub>, and H<sub>2</sub>O(g). The argon is sampled at various points in the system to determine purity and effectiveness of the purification train. Normal purity during operation is 0.3 ppm O<sub>2</sub> in the environmental chamber.

## b. Argon Loop Design

The blower to provide argon flow is a two-stage axial fan rated at 1100 cfm at a  $\Delta P$  - 1.3 lb at 150°F. The fan is sealed into the system and utilizes special seals, lubricants and insulation to minimize outgassing and thermal decomposition. Plumbing is 6 in. diameter carbon steel surface treated to minimize oxidation. All joints are either welded or "O" ring sealed. Total  $\Delta P$  in the loop is expected to be less than 1 psi at t<sub>max</sub> = 300°F.

The water loop extracts heat from the argon. A small pump circulates the water through a flow rate control valve to the heat exchanger and out to a cooling tower which recools the water.

## c. Water Loop Design

Design specifications are shown below:

Type	=	closed cycle forced circulation
Max. Temp. Argon (inlet)	=	300°F
Max. Temp. Argon (outlet)	=	150°F
Max. Temp. Water (outlet)	=	85°F
Max. Temp. Water (inlet)	=	75°F
Max. Flow Rate (argon)	=	51,500 lbs/hr
Max. Flow Rate (water)	=	10,000 lbs/hr

Standard tube-in-shell design connected to argon system by "O" ring seals. Cooling water from closed circuit pressurized plant water cooling system.

The three loops are interlocked by the necessary instrumentation and controls to provide stable operation. Instrumentation and control consist of the following:

(1) Temperature readout of loop, environmental chamber and cooling system by chromel-alumel and platinum-platinum/rhodium thermocouples.

(2) Pressure readout and automatic control of argon pressure both in the loop and in the environmental chamber.

(3) Rubidium flow rate readout and manual control by a liquid metal pump and flowmeter system.

(4) Argon and water cooling systems flow rates by automatic control of temperature and flow rate.

(5) Manual loop heater control.

At present two primary loops have been built for this unit; the first was of 316 stainless steel. This loop was run for 172 hrs at 1550°F at approximately 15% vapor quality of rubidium to check out design concepts for the loop and to gain operating experience. The Cb-1 Zr loop has been fabricated, installed and is presently operating at 1780°F, 160 psia argon pressure at approximately 5 to 10% vapor quality. It has been operating for 100 hrs under design conditions (continuous boiling) without malfunctions of any type. The loop system will be shut down after 1000 hrs of operation and examined for corrosion effects.

### 3. Thermodynamic Measurements

Figure 3 is a drawing of the test apparatus used to measure the vapor pressure and latent heat of vaporization of rubidium. The cylindrical Inconel vessel is about 6.0 in. dia. X 12 in. high. The condensate collection reservoir volume is about 30 cc. It has two Co-60 radiation sources (about 0.5 mc each) fitted at top and bottom adjacent to reduced volume sections. The volume of the reservoir has been calibrated between these two sources for measurement of the rubidium boiling rate during operation.

The boiling apparatus is evacuated and charged with about three pounds of rubidium metal; then placed in the thermal radiation shield assembly and the entire unit placed in a vacuum chamber. All operations are conducted in a vacuum chamber ( $10^{-4}$  mm Hg) to eliminate convective and conductive heat loss. Test runs consist of establishment of thermal equilibrium between the boiling vessel and shield assembly (heater) at a number of successive temperatures between 1000 and 1800°F. At each equilibrium point the rubidium saturation temperature and vapor pressure will be recorded and  $\Delta H_{\text{vap}}$  measured.

To measure  $\Delta H_{\text{vap}}$  the following must be known:

- a. Heat loss from the boiling apparatus (determined during a no-boiling run)
- b. The total boiling heat input.
- c. The boiling rate.

The rate of boiling will be determined by measuring time required to fill the calibrated volume in the condensate collection reservoir. (The density of Rb(liquid) as f(temperature) will be measured in a separate apparatus).

During boiling operation the condensed Rb(liquid) flows into the condensate reservoir. The change in count rate that will be noted on the radiation readout instrument when the Rb(liquid) shields each of the Co-60 sources will indicate



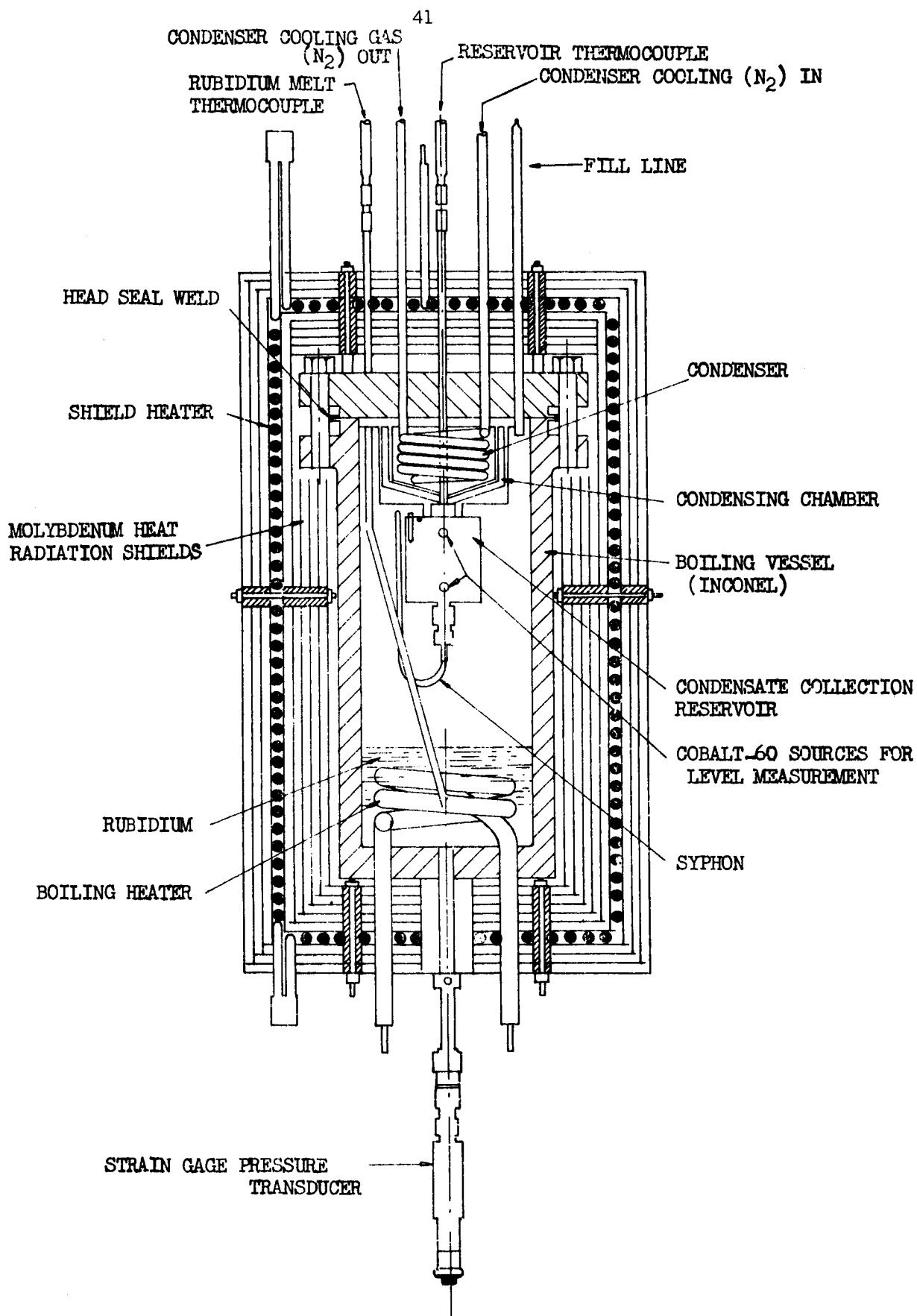


FIGURE 3. RUBIDIUM BOILING APPARATUS.

the time rate of boiling. The rubidium temperature is measured with protected chromel-alumel thermocouples assumed accurate to  $\pm 5^{\circ}\text{F}$  at  $1000^{\circ}\text{F}$  and  $\pm 9^{\circ}\text{F}$  at  $1800^{\circ}\text{F}$ . These thermocouples are to be calibrated in the near future.

From these measurements then the latent heat of vaporization of rubidium,  $\Delta H_{\text{vap}}$ , can be calculated.

$$\Delta H_{\text{vap}} = \frac{q \cdot t}{vp}$$

where

- $q$  = boiling heat input, cal/sec
- $t$  = time to fill the calibrated reservoir, sec
- $V$  = condensate reservoir volume, cc
- $P$  = condensate density, gm/cc

The syphon shown in Figure 3 will empty the condensate reservoir automatically when it is full and allow the continuous operation of this instrument without shutdown within the temperature range for which it is designed.

The pressure sensitive transducer to measure the rubidium vapor pressure is a 0-250 psia strain gage type produced by CEC. It is designated model number 4-326. This unit measures the total pressure exerted by all vapor species present at the designated temperature.

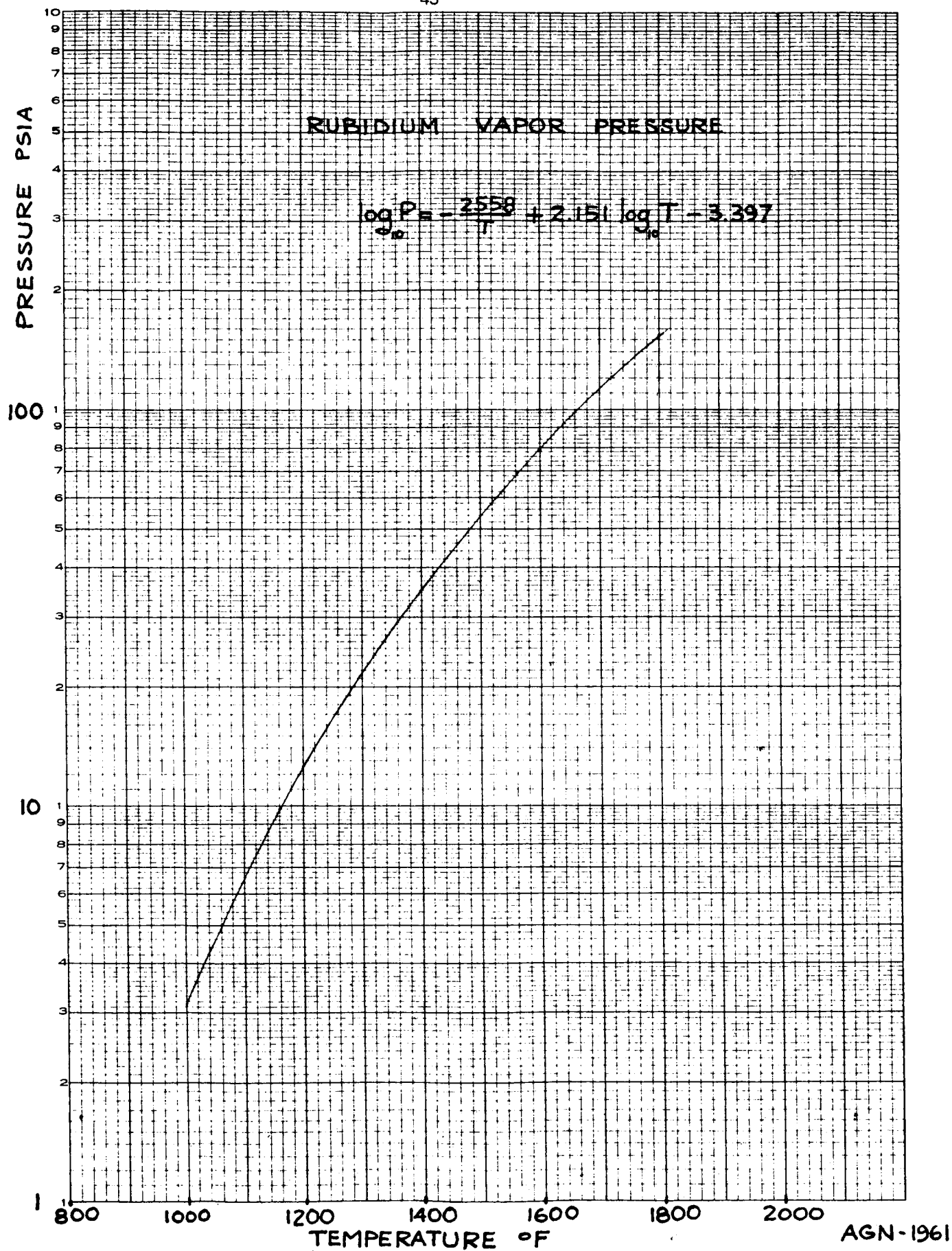
Figure 4 shows the vapor pressure data developed to date. This curve represents 60 data points in the temperature range shown. The thermocouples and the pressure sensitive transducer used in this work have been calibrated. The experimental limits of error is  $\pm 3\%$ .

Figure 5 shows top and cross-section views of the capsule used to measure the density of liquid rubidium as a function of temperature. This is a simple "spark plug" type level indicator. When the liquid metal expands upward in the riser tube as the capsule is slowly heated, it successively shorts out the four graduated electrodes. The interior capsule volume has been previously calibrated and thus the liquid metal density can be measured. Unfortunately, the rubidium vapor present in the capsule caused erratic operation of the electrodes above  $1350^{\circ}\text{F}$  so that density data could only be obtained up to this temperature. This occurred with the capsule pressurized to 45 psia with argon at room temperature; this is sufficient to prevent boiling at  $1800^{\circ}\text{F}$ . Figure 6 shows the density vs. temperature data that has been measured to date. The thermocouples used have not been calibrated so this curve must be considered preliminary.

A new apparatus will be used to measure the density of liquid rubidium up to  $1800^{\circ}\text{F}$ . The device consists of an overflow pycnometer sealed into a pressurized capsule fabricated from Haynes 25, a cobalt-base alloy. The atmosphere inside the capsule will be purified argon. Prior to operation, the calibrated rubidium reservoir inside the capsule will be filled; the capsule pressurized with argon, sealed, and then the entire unit placed inside a furnace and uniformly heated to the desired temperature. In operation the rubidium in the calibrated vessel will overflow through a capillary tube due to its bulk

FIGURE 4

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E-1549

# *RUBIDIUM DENSITY CAPSULE*

E-1549

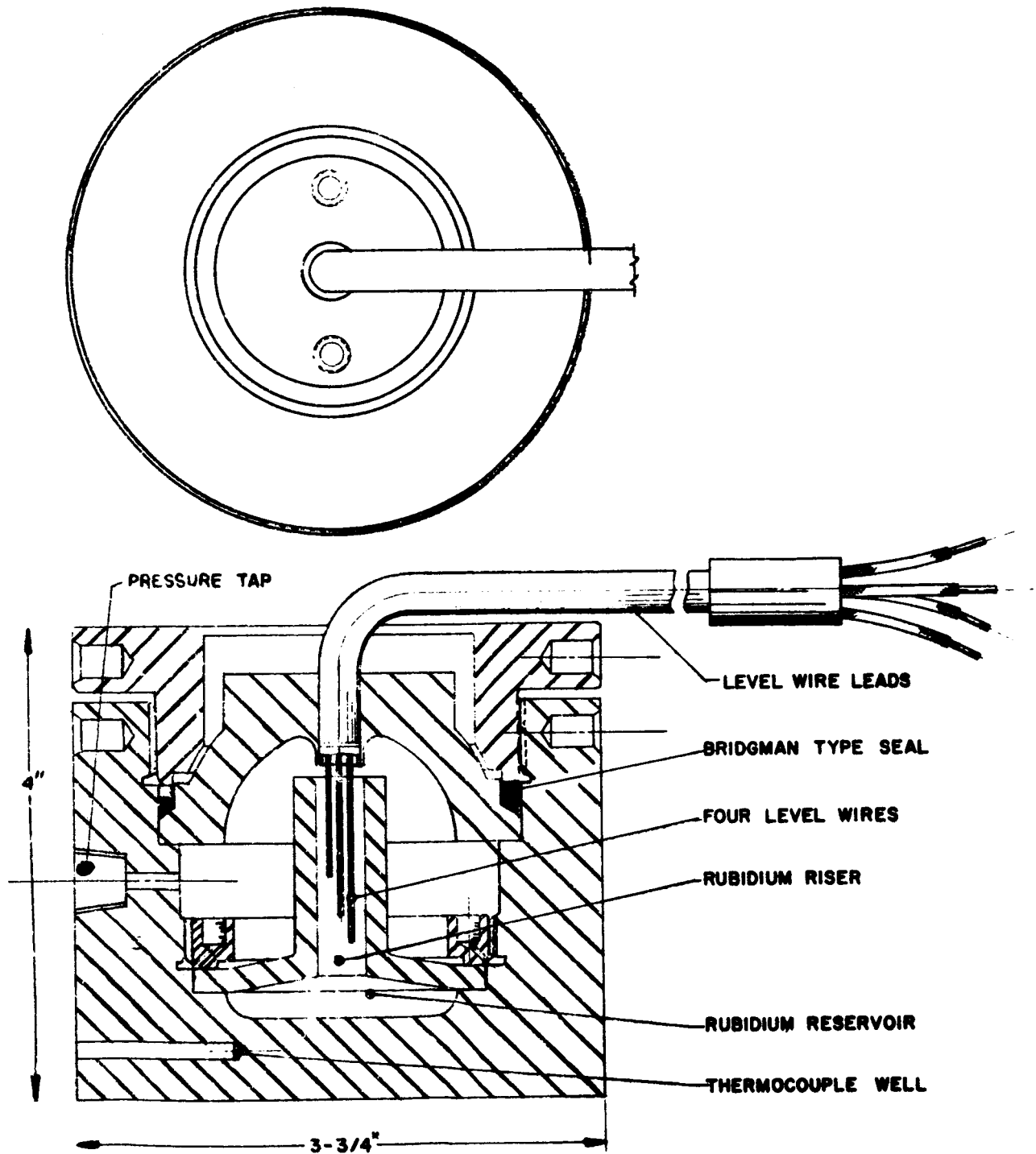
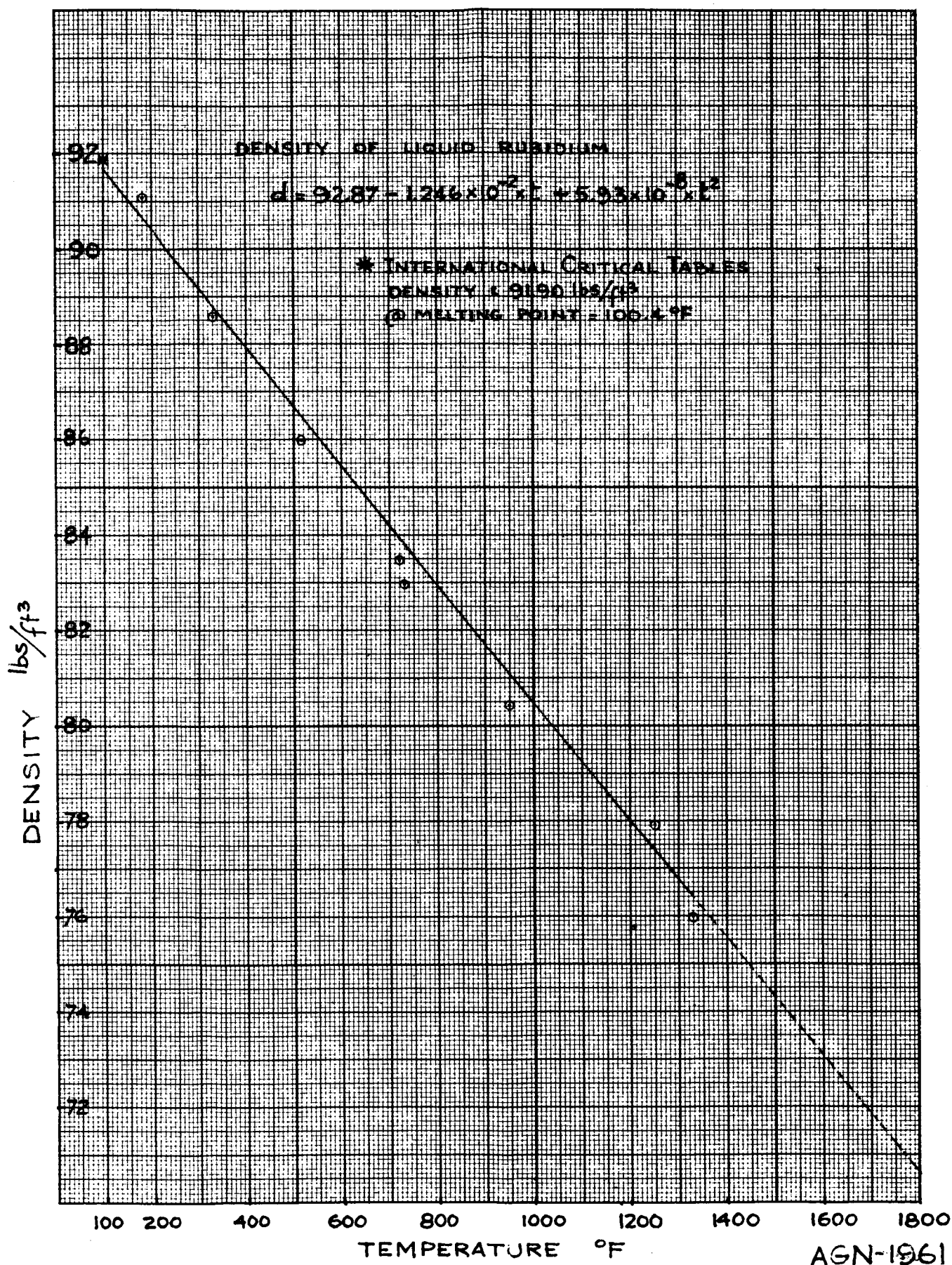


FIGURE 5

FIGURE 6



thermal expansion. The overflow of rubidium is caught in a small thimble. Upon cooling, the weight of rubidium left in the calibrated vessel divided by the vessel volume will yield density of the liquid at the specified temperature. Thermocouples will be used to measure the temperature of the capsule during operation.

## B. CESIUM PROGRAM

Aerojet-General Nucleonics will begin a Cesium Evaluation Program in July of 1961. This program will develop the same type of data now being generated for rubidium by AGN. This data will permit the objective comparison of cesium, rubidium, and potassium for use as a working fluid in high power density and light weight nuclear turbo-generator space power systems. The phases of the program are described below:

### 1. Phase I - Loop Fabrication

Design and fabricate a forced-convection boiling heat transfer loop simulating power conversion system characteristics to determine the nature and extent of corrosive and erosive attack by cesium under dynamic conditions. Test sections will include straight and curved pipes, valves, pumps, and orifices. The range of cesium liquid velocities will be 10 to 20 ft/sec.

The heater will be designed to provide vaporization of liquid cesium to about 50% vapor quality, at least at the lower fluid velocities.

### 2. Phase II - Loop Operation

Loop operation at low fluid velocities will produce cesium temperatures at the heater exit and cooler outlet of 1800° to 2000°F and 1200° to 1400°F, respectively. The loop will be run continuously for 1000 hrs under these conditions. After operation the loop will be dismantled, sectioned, and be given complete metallurgical examination.

### 3. Phase III - Thermodynamic Data

a. Necessary equipment for the determination of  $C_p$  as a function of temperature for liquid cesium will be designed, built, and the experiments will be conducted.

b. Equipment necessary for the measurement of vapor pressure as a function of temperature and the latent heat of vaporization will be constructed and the required data measured. The vapor pressure, the specific heat, the latent heat of vaporization will be measured over the temperature range from 1000° to 2000°F.

c. Entropy, heat content, and vapor specific volume properties will be calculated from the above listed experimental data.

## C. SNAP VIII - MERCURY PROGRAM

Aerojet-General Nucleonics is a subcontractor to the Power Equipment Division of the Aerojet General Corporation on the SNAP VIII program. This program

is supported by NASA and is developing a mercury rankine power plant for space power applications. AGN is developing the mercury boiler and condenser-radiator for the system. Among the facilities that have been built for this program are a large boiling mercury heat transfer experiment and a mercury condensing experiment. Tests are being conducted to determine heat transfer ratio, pressure drop, and liquid-vapor interface stability.

In addition, a mercury corrosion program is being conducted to evaluate various alloys from the standpoint of solubility, stress corrosion, and intergranular penetration. This program is, in the near future, scheduled to operate large sized (60 Kwe) purified corrosion loops to evaluate promising alloys for mercury containment.

## LIQUID-METALS PHYSICAL PROPERTIES PROGRAM\*

PRATT &amp; WHITNEY AIRCRAFT

## RARE GAS SOLUBILITY TEST

## Description:

Theoretical calculations, by two different methods, have shown that great uncertainties exist in predicting the solubility of gases in liquid metals. An apparatus similar to Grimes et. al. has been constructed from type 316 stainless steel which will be used to obtain data with helium in lithium to 1500F. The gas and liquid metal are equilibrated at test temperature, transferred to a low temperature pot, and stripped with a second gas. The gas concentration is then obtained by mass spectrometry. The equipment can also be used with radioactive materials.

## Status:

The equipment has been fabricated and preliminary data have been obtained. The data are in substantial agreement with theoretical calculations based on the hole method. Test data will be obtained to 1500F with helium and lithium.

## ELECTRICAL RESISTIVITY TEST

## Description:

The determination of the electrical resistivity of liquid metals. A type 347 stainless steel tube 16 inch long by 0.56 inch inside diameter was filled with alkali metal and sealed under vacuum. Contact points were made on a 12 inch section, the tube then placed in a nickel block heat sink and carefully insulated. Measurements can be made to 1600F. Resistivity measurements are made by means of a high sensitivity electrical circuit.

## Status:

The resistivity of lithium and NaK to 1600F have been completed. Least square equations are: ( $t = ^\circ\text{C}$ )

$$\text{Li:} \quad (\text{microhm-cm}) = 17.20 + 5.24 \times 10^{-2} t - 4.46 \times 10^{-5} t^2 + 2.28 \times 10^{-8} t^3$$

$$\text{NaK (56\% Na)} \quad (\text{microhm-cm}) = 29.55 + 56.63 \times 10^{-3} t - 22.15 \times 10^{-6} t^2 + 46.95 \times 10^{-9} t^3$$

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\*Presented by Robert Cleary, Pratt & Whitney Aircraft.



## THERMAL CONDUCTIVITY CALCULATIONS

## Description:

Using the Weideman-Franz relationship and a Lorenz number obtained from preliminary thermal conductivity data of Ewing and Grand (unpublished data) for lithium and a value of  $2.45 \times 10^{-8}$  for NaK the thermal conductivities have been calculated.

## Status:

$$\text{Li: } K (\text{watts/cm } ^\circ\text{C}) = (3.79 - 42.1 T^{-1} - 2.93 \times 10^{-3} T + 1.06 \times 10^{-6} T^2)^{-1}$$

$$\text{NaK (56\% Na); } K (\text{watts/cm } ^\circ\text{C}) = (3.234 + 468 T^{-1} - 24.74 \times 10^{-4} T + 19.16 \times 10^{-7} T^2)^{-1}$$

## LIQUID METAL VISCOSITY

## Description:

The determination of liquid metal viscosities to 2200F by means of a rotating cup viscometer. The equipment consists of an Inconel chamber, molybdenum cup and spindle and a calibrated torsion wire. Provision has been made for evacuation and subsequent inert gas operation. The system can readily be adopted for rotating sphere operation.

## Status:

The equipment is presently being assembled and should be operable by May 30, 1961.

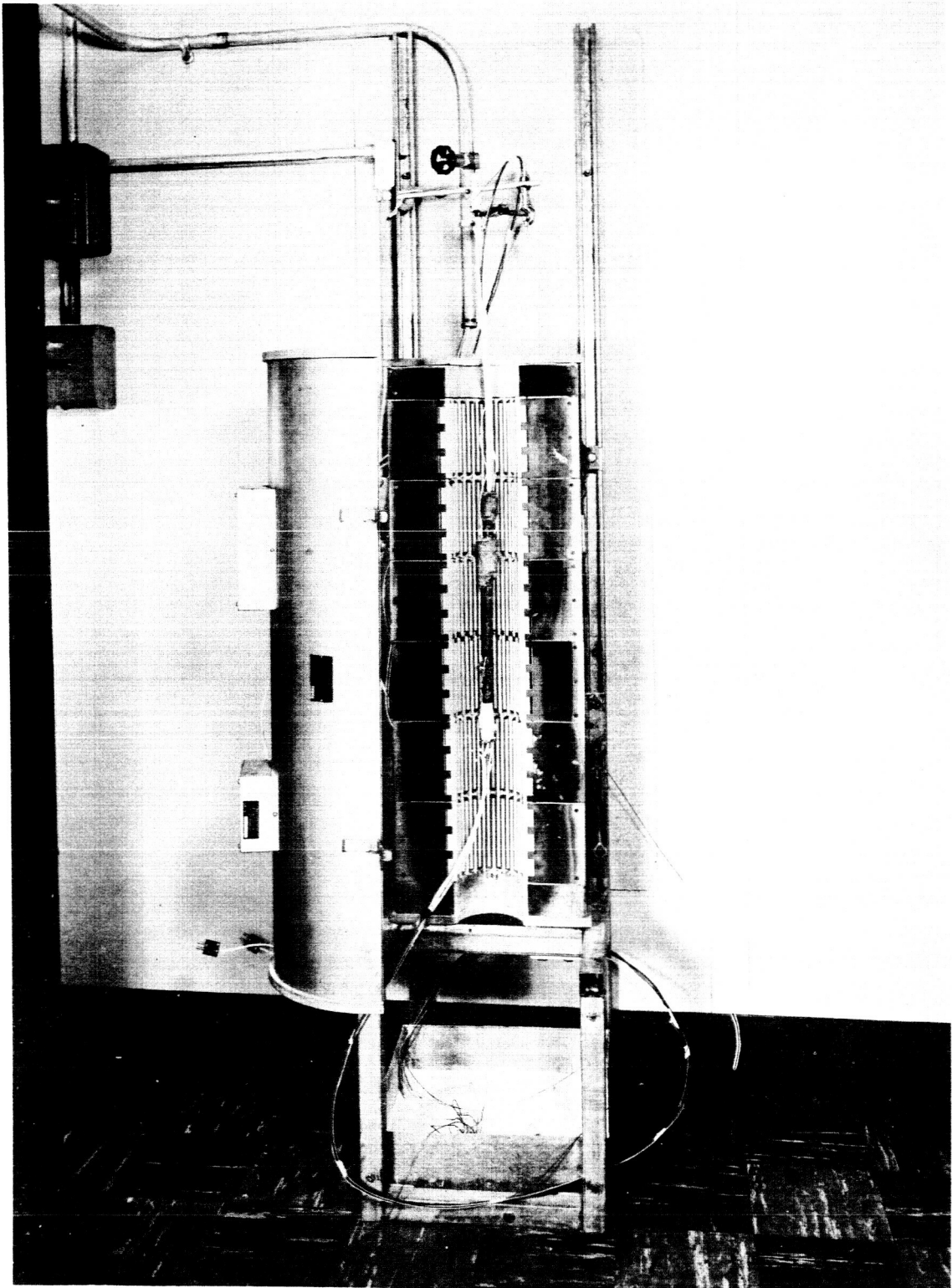
## VAPOR PRESSURE AND GAS PROPERTIES

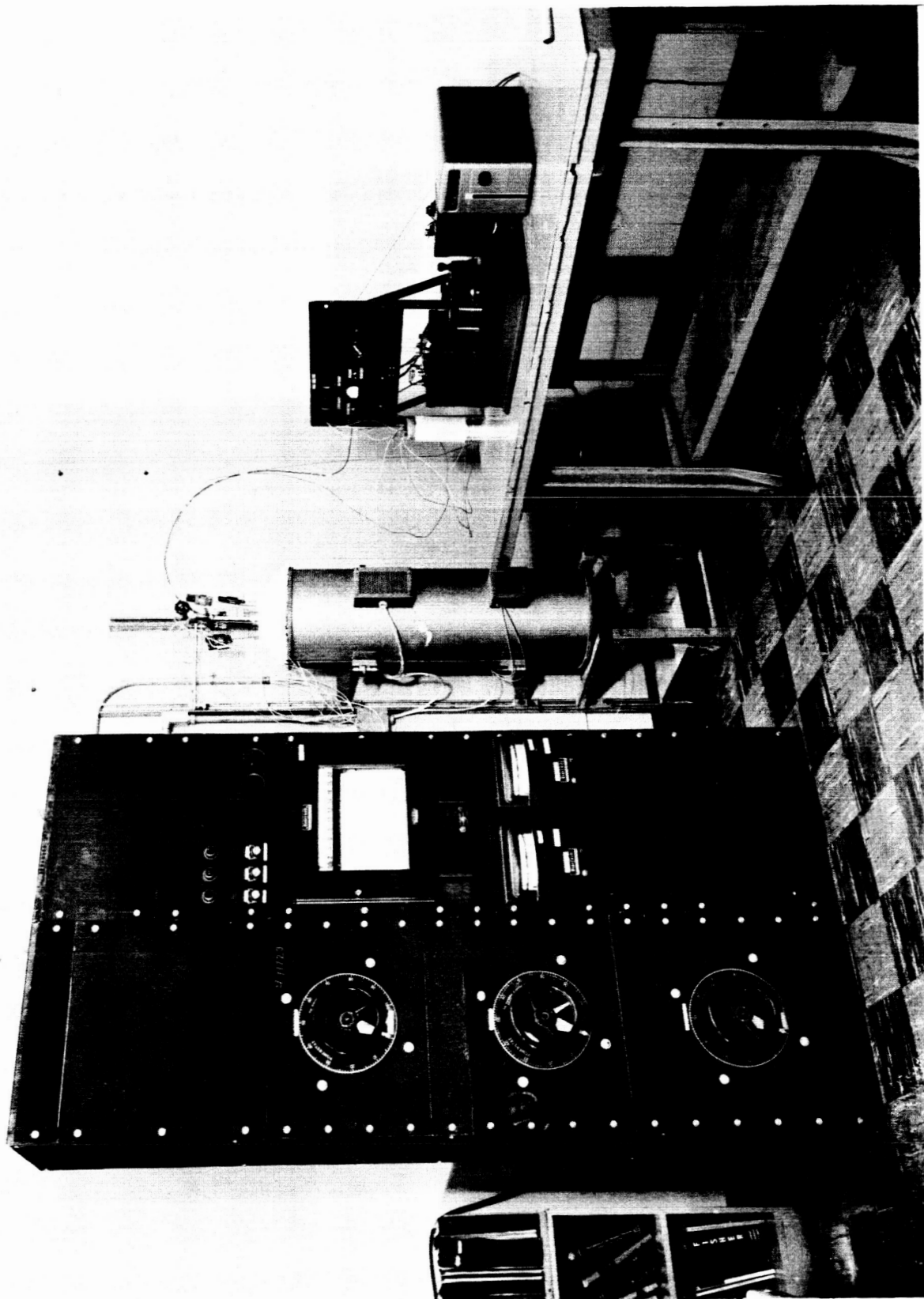
## Description:

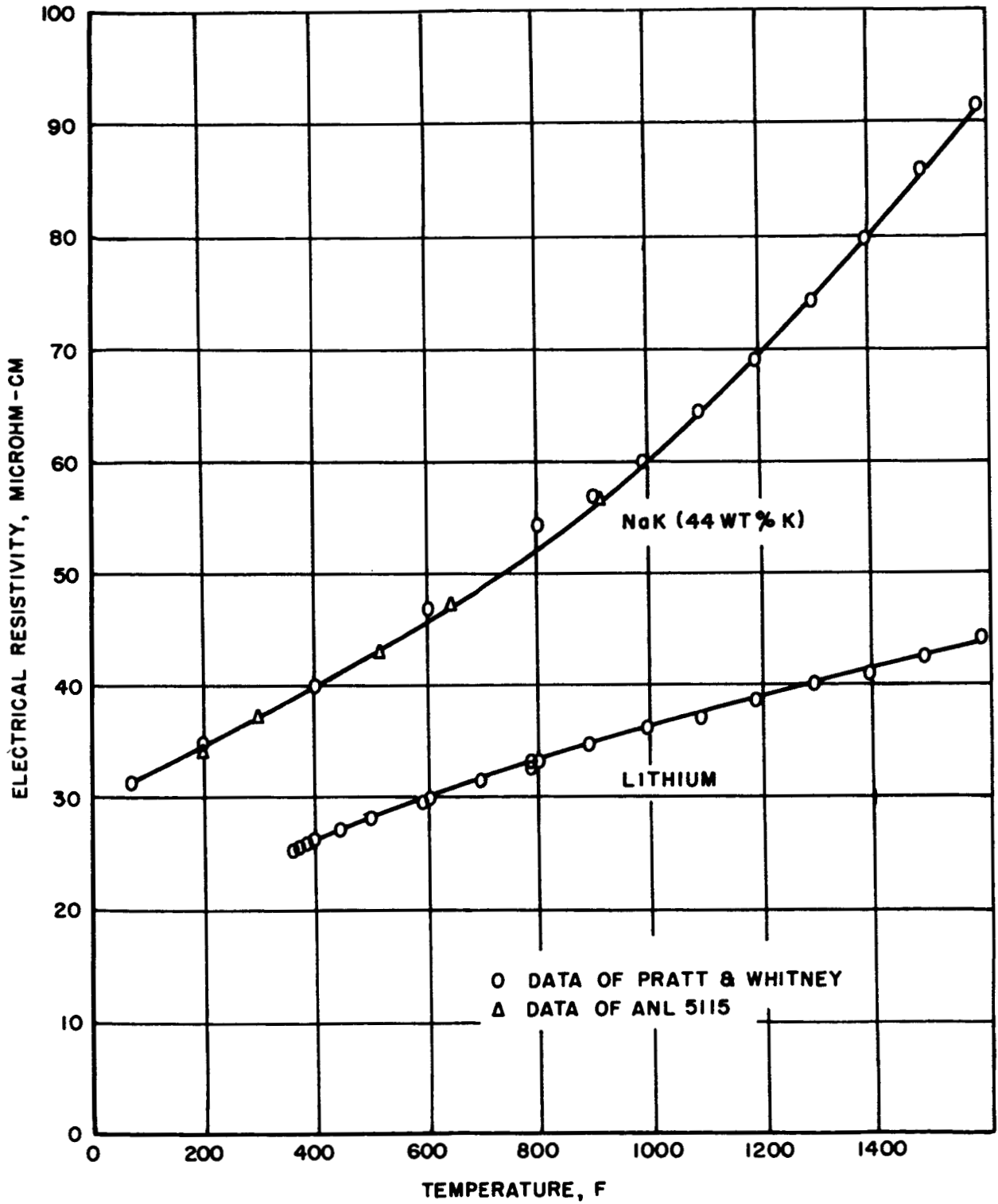
Determination of vapor pressure and vapor densities of liquid metals at temperatures up to 3000F.

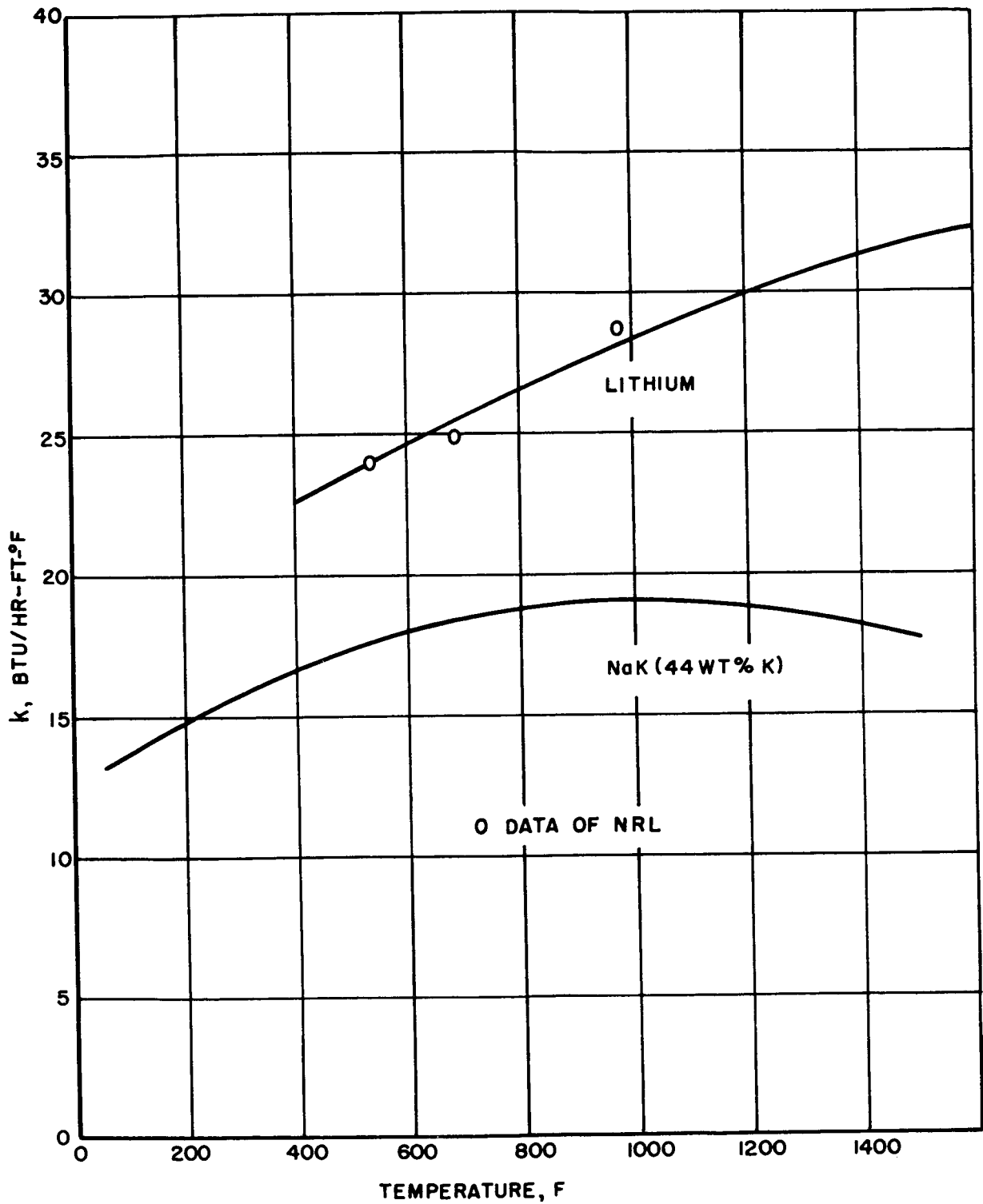
## Status:

Equipment is presently being designed.





ELECTRICAL RESISTIVITY OF LIQUID LITHIUM AND NaK

THERMAL CONDUCTIVITY OF LIQUID LITHIUM AND NaK

**Columbia University**  
**in the City of New York**

NEW YORK 27, N. Y.

DEPARTMENT OF CHEMICAL ENGINEERING

April 13, 1961

Alexis W. Lemmon, Jr.  
 Battelle Memorial Institute  
 505 King Avenue  
 Columbus 1, Ohio

Dear Mr. Lemmon:

We are actually only beginning again our work on liquid metals, and are not in a position to provide much prepared material. However, if I can get any drawings out of my assistants before the meeting, I will send or bring them to you.


The topics we are starting to work on include the following:

- (1) Heat transfer in the condensing of K and Rb vapors at relatively low temperatures;
- (2) Approximate boiling transfer in the same equipment (pool boiling);
- (3) Vapor pressure of Rb and probably Cs up to approximately 100 lbs per square inch;
- (4) Thermoelectric potential of K and Rb against standard metals;
- (5) Pool boiling heat transfer to K, a more accurately and to higher heat flux than under (2) above;
- (6) Critical temperature and pressure of Rb, K, and Na, as feasible in that order.

I could spend anywhere from ten minutes to one-half hour or more describing the above topics qualitatively at a blackboard.

I have a reservation on TWA 371, arriving Columbus 9:35 p.m. Sunday, April 23rd, and would appreciate a reservation for that night at the Olentangy Inn.

Cordially,

  
 Charles F. Bonilla,  
 Professor.

CFB/mh

NASA-CLEVELAND, OHIO E-1459

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